COURSE

OF

MILITARY INSTRUCTION,

&c.

Printed by J. INNES, Wells-street, Oxford-street, London.
The Wood Engravings by R. AUSTIN.

COURSE

OF

MILITARY INSTRUCTION,

ORIGINALLY

COMPOSED FOR THE USE

OF THE

Royal Engineer Department.

BY

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VOLUME III.

Containing Elementary Fortification.

London:

PRINTED FOR JOHN MURRAY, ALBEMARLE STREET.

1817.

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COURSE

OF

ELEMENTARY FORTIFICATION,

&c.

CHAP. XVII.

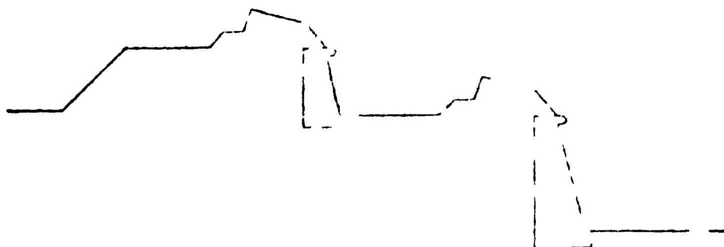
OF FAUSSEBRAYS, CAVALIERS, ORILLONS, AND RETIRED FLANKS.—CONCAVE AND DOUBLE FLANKS ALSO EXPLAINED.—OF THE TOWER BASTION SYSTEM OF FORTIFICATION:—AND OF RETRENCHMENTS.

IN the concluding parts of the preceding volume, some of the most useful general principles, which ought to be kept in view, in constructing a bastionary front of fortification, were explained. Many points, however, of considerable importance, have still been left undiscussed, such as the most suitable form, breadth, and depth, of the various ditches, the width of the covered way, &c. &c. But upon the whole, it is much best for the learner, not to attempt to enter too deeply into the principles of defensive fortification, until he has previously made himself thoroughly acquainted with the most approved system and means of attack. In continuing to treat of the former subject, I shall therefore confine myself to a

simple explanation of the general nature of such works and outworks, as have not yet been defined, without pretending to reason at large upon their advantages or defects.

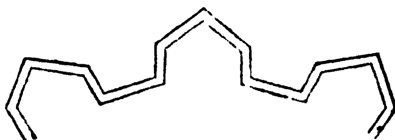
The principal variations, which have taken place, at different times, in the construction of the main inclosure of a regular fortress, shall now be noticed.

In the more early periods of modern fortification, it was customary to form the whole of the body of the place with double ramparts and parapets, which were not separated from each other by an intervening ditch, their relief being so regulated, that the interior line of works could fire over the other, as is represented in the annexed section.



When this construction was used, the lower and more advanced rampart of the two was called A FAUSSEBRAY, the terreplein of which was usually placed on the natural level of the original ground.

The outline of the main inclosure, of a place so fortified, must of course be represented by a double line, in the following manner.



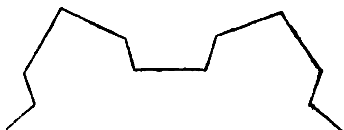
The objections to a faussebray are as follows. After an enemy's first batteries are opened, the men posted in it are liable to be destroyed, not only by enfilading shot and shells, but also by the rubbish and splinters of the interior revetment which is immediately behind them; and which, when effectually breached, may bury the whole or the greater part of the terreplein of the faussebray under its ruins. Owing to the small relief of this work, which has no command over the glacis, it is also incapable of impeding a besieging army by its fire, in their more distant operations, nor can it even see them, until they are established near the crest of that work, on the brink of the covered way. Moreover experience has shown, and the same will indeed appear evident on a very little reflection, that, in case of an attack by assault or otherwise, one high reveted scarp is much preferable to two low ones. For these reasons, the use of a continued faussebray was gradually abandoned.

Still it was considered of importance, that some parts of the main inclosure should be able to oppose the enemy's progress by a double line of fire, and therefore cavaliers, double flanks, and tenails, were generally adopted in preference.

A CAVALIER denotes any work constructed within another, and raised to such a height above it, as to be able to fire conveniently over it.

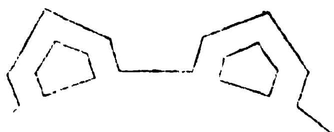
Cavaliers are seldom or never erected behind curtains, but it is very common to place them in bastions, and more especially in full bastions.

To explain the nature of these works, we shall first draw part of the outline of a regular fortress, consisting of two bastions and a curtain.



The cavalier is usually constructed of the same form as the bastion itself, having two faces and two flanks, parallel to those of the bastion.

Draw two cavaliers, accordingly, one in each bastion of your figure, and complete the form of them, by inclosing them at the gorge.



Sometimes a cavalier is merely raised above the level of the terreplein of a full bastion, without any intermediate ditch in front of it.

In that case, the section of the work, if reveted, will resemble that of the interior rampart and faussebray of the former system; so much so, that the first figure of this chapter, may serve equally well to represent a section through the face or flank of a bastion constructed with a cavalier of the above description. And indeed, the interior line of a place fortified with a faussebray may be considered as a kind of continued cavalier.

There is however a great difference in the relief of the two sections, that of the cavalier bastion being the boldest, so much so, that both the upper and lower parapets of this system have a considerable command above the glacis and surrounding country, whilst the parapet of the faussebray has no effectual command whatever over either of them, as was before explained.

Sometimes a cavalier has a ditch in front of it, and then it may serve not only to fire over the bastion, but also as a retrenchment for that work.

Here it is proper to remark, that the term RETRENCHMENT implies any interior work, which is constructed within or in rear

of another, for the purpose of strengthening it; and A WORK, which is so strengthened, IS SAID TO BE RETRENCHED.

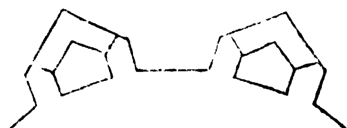
The term INTRENCHMENT, on the contrary, implies an independent work, constructed in the open field, without a reference to the support of any other adjoining work, immediately in front of it, to which it can be considered subservient.

Having made these necessary definitions, we shall proceed with our subject.

When a cavalier is used as a retrenchment for the purpose of stopping an enemy's progress, in case he should effect a practicable breach near the point of the bastion; in addition to its own ditch, which is essentially necessary, there must also be two other ditches connected with it, which being cut right across the terreplein of the bastion on each side of the cavalier, serve to interrupt the communication, so as to prevent the besiegers, after storming the breach, from being able to penetrate any further.

These ditches, as well as that of the cavalier, have usually reveted scarps and counterscarps; and their scarp is surmounted by a proper parapet, which may serve either for cannon or musquetry, and which is usually of the same height nearly, as that of the body of the place.

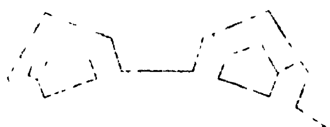
The works, thus constructed, on each side of a cavalier, are called CUTS, and it is to be observed that the same term is always used in speaking of any very short line of work, formed for a similar purpose.



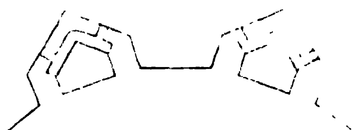
To exemplify this kind of obstacle, in your present figure, you will draw right lines from the shoulders of your cavaliers to the faces of the opposite bastions, in a direction perpendicular to the latter, or nearly so.

These last drawn lines will represent the scarp lines of cuts, which may be formed in support of your cavaliers. It is to be observed, however, that the parapet or scarp line of a cut is not always laid out in one continued right line. Sometimes it may be constructed with one half of it more retired than the other: the two portions of it, when thus formed, being nearly parallel, and joined by a right line, called A RETREAT, which may be made perpendicular to them, or nearly so.

Alter the cuts in your left bastion accordingly, forming them in two portions connected by retreats, in the manner which has just been explained, and let that part of each, which adjoins to the cavalier, be the most retired.



This being done, complete your figure by drawing the ditches, observing, however, that no ditch is necessary, and consequently none must be represented, in those parts of each cavalier, which are in rear of the cuts.



Cavaliers serving also as retrenchments, such as those shown in our present figure, are called DEFENSIBLE CAVALIERS, in order to distinguish them from the COMMON CAVALIERS, before described, which have no ditches in front of them, and are not supported by cuts.

In large bastions, the distance between the scarp line of the faces of a defensible cavalier, and the interior crest of the parapet of the faces of the bastion, in which it is constructed, should not be much less than about 20 yards; otherwise it would not allow sufficient space for the terreplein of the bastion and ditch of the

cavalier, neither of which should be less than 10 yards wide, if possible: nor should the above distance exceed 26 yards, because in that case, the cavalier could not have a proper command over the glacis, unless it were raised to a very inconvenient height.*

It was before stated, that the terreplein of the bastions is entirely cut through by the ditches of the cuts adjoining to the cavalier. These ditches are therefore covered in flank by the scarp revetment only, which may there be formed with a ridge at top, like that of a batardeau, in order to prevent an enemy from penetrating over it.

* In a fortress, having profiles of so bold a relief as those explained in Chapter VI, and Plate 2d, of this work, if cavaliers were constructed within the bastions at the distance of 20 yards, it would be necessary to give the parapet of each cavalier a command of at least 14 feet 6 inches, over that of the body of the place: otherwise it would not be able to fire upon the foot of the glacis, without incommoding the defenders of the bastion in front of it. Now as the bastion itself, according to the above profiles, has a command of 25 feet 6 inches over the country, the total height of our supposed defensible cavalier would be no less than 40 feet above the ground line; and of course, by increasing the distance, the relief of the cavalier would also require to be increased in proportion, in order to produce an equally plunging fire.

If, however, the object of having a combined fire, from the cavalier and bastion, upon the glacis, should be given up, and the former is supposed to act against the enemy's more distant works only, then a less commanding profile will answer the purpose. In Cormontaigne's profiles for example, he gives his defensible cavalier a command of 8 feet 6 inches only over the bastion, at the distance of about 40 yards. *(See Œuvres Posthumes de Cormontaigne, Vol. I.)*

It is to be remarked, that a very commanding cavalier offers the greatest obstacle to an enemy's operations in general; but as a retrenchment it is less serviceable than a lower one, after the enemy have established themselves in the bastion in front of it; because the musquetry fire of a high cavalier cannot well be brought to bear upon the whole terreplein of the bastion, without increasing the dip of the parapet, and consequently weakening the crest of it, to an inconvenient degree.

In a defensible cavalier, the top of the masonry should not be raised higher than the interior crest of the parapet of the bastion, by which it is covered. With respect to a common cavalier, it is much best that it should not be reveted at all, in the manner represented in the first figure of this chapter. In such a work, it not being intended as a retrenchment, masonry would only be a useless expense; and might even by its splinters be prejudicial to the defenders of the bastion, unless removed to a considerable distance in rear of the faces of that work, which removal would add to the expense in another point of view, by rendering a bolder relief necessary, in order to produce an equally plunging fire. Unreveted cavaliers, on the contrary, may be placed much nearer to the faces without inconvenience. A free space of 12 or 13 yards for instance, left as a terreplein, between the foot of the scarp of the cavalier, and the parapet of the bastion, will be quite sufficient.

It may perhaps appear scarcely necessary to mention, that every cavalier must have ramps or staircases towards its gorge; in addition to which a defensible cavalier must also have a proper communication with the bastion in front of it, by means of sally-ports leading into its own ditch, and staircases or ramps to ascend from thence upon the terreplein. These are indispensible in all retrenchments, or works formed with ditches; and in all other obstacles used in fortification, such as palisades, &c. which have no ditches; barriers, or other gates, for the purposes of communication, are no less necessary. This being explained, it will be understood, that in treating of the various works, which may come under our consideration hereafter, such communications, although they may not be specifically mentioned, are always implied.

Double flanks, which I shall next proceed to explain, have seldom been used, except when the main inclosure of a fortress has been formed with what are called orillons. The rules for this construction are as follows.

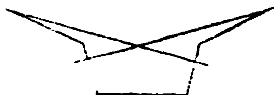
Draw first a front of fortification in the usual manner, and upon each flank mark a point at the distance of about one third of its length, measuring from the shoulder, backwards.*



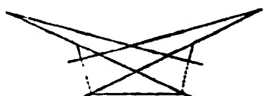
Dot the remaining part of each flank, namely that which is comprehended between the said point and the curtain.



From the salient angle of each demi-bastion, draw a line intersecting the opposite flank, and passing through the point which was before marked upon it.



Produce also the lines of defence of your front of fortification, outwards, beyond the extremities of the curtain.



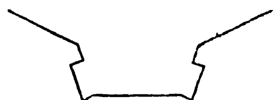
Parallel to each of your original flanks, and in rear of them, at the distance of about one sixth part of their length, which in real practice may be 9 or 10 yards, draw lines bounded by the last drawn oblique lines.

This being done, rub out all those lines of your figure, which fall without the original front of fortification.



The parallel lines, last drawn, will represent what are called retired flanks.

Rub out the dotted lines, and other parts of your present figure, which will become superfluous after the retired flanks are drawn.



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* This is Vauban's rule according to St. Paul (See that author's *Traité Complet de Fortification).* Others recommend setting off about 14 yards, or one fourth of the length of each flank only.

A front of fortification, whose flanks are not constructed in one continued right line, but with a retreat, in the manner now represented, is said to be formed with ORILLONS AND RETIRED FLANKS. The latter having just been explained, it is only necessary to observe, that the projecting part near the shoulder of each bastion, constitutes what is called an orillon.

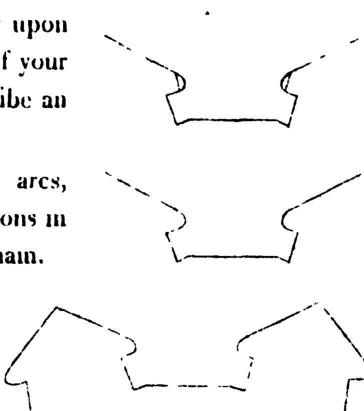
In this construction you will also observe, that there are BREAKS IN THE CURTAIN, near each extremity of it.

Orillons were not often made angular like those of our present figure. They were more usually curved.

To exemplify this construction: upon the small remaining part of each of your original flanks, as a chord, describe an arc outwards.*

Rub out the chords of these arcs, and the representation of the orillons in their proper curved form will remain.

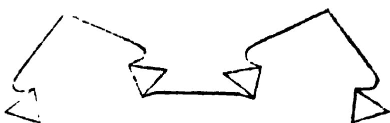
Add to your figure, by converting your two demibastions into whole bastions of the same construction.



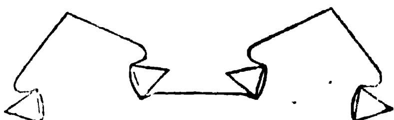
Retired flanks are sometimes made in the form of arcs of a circle; and then they are called concave flanks; the common mode of constructing which is as follows.

* Vauban's method of describing these arcs is said to have been as follows. He bisected each small portion of his original flank by a perpendicular, which he produced inwards towards the capital of the same bastion. Then from the outward extremity of the retired flank, he drew an oblique line to the adjoining angle of the shoulder of the original outline, intersecting the above perpendicular. The point of intersection, thus found, was used as a center for drawing the curve.

Upon each of your present retired flanks, as a base, describe an equilateral triangle outwards.



From the vertex of each of these triangles, as a center, with a radius equal to one side, describe arcs standing upon your retired flanks, as chords.



These arcs will represent your retired flanks in their new form. You will therefore rub out the equilateral triangles entirely; and the figure of two bastions with orillons and CONCAVE FLANKS will be complete.



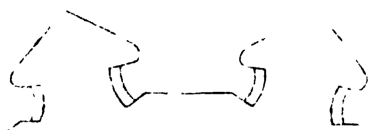
That part of an orillon, which faces towards the curtain, is called THE REVERSE OF THE ORILLON, and is usually constructed without any parapet.

The reverse of each orillon being directed upon the point of the adjoining bastion, it follows that no part of this line can be seen by a person, standing any where in front of the said point, as for instance in the covered way or on the crest of the glacis. But it is there, that an enemy must necessarily establish his principal batteries towards the close of a siege, partly to effect a breach in the faces of the bastions, near the salient angle, and partly for the purpose of silencing the fire of the flanks. Now from what has just been said, it will readily be understood that none of these batteries can see into the reverse of an orillon. Consequently in bastions so constructed, one gun may be placed at the outward extremity of each retired flank, which may be so completely covered by the orillon, as not to be injured by the direct fire of

any of the besiegers' batteries, and which yet will itself be capable of seeing into and defending the breach. Such was the reason, which caused the very general adoption of orillons and retired flanks, in the more early periods of modern fortification.

In process of time, however, after the use of shells, and of enfilading gun batteries, became more common, it was found that the orillons could no longer protect their retired guns, with any degree of certainty; and therefore this expensive construction was abandoned, in favour of the common right-lined flank, which may be built with about one third less masonry.

Having made this remark, we shall next proceed to explain the nature of double flanks.



Produce the reverse of each of your orillons and the breaks of your curtains, towards the adjoining capitals of the bastions, and connect these produced lines by a second set of arcs, drawn parallel to your concave flanks.

The last described arcs represent the SECOND FLANKS of a fortress constructed with double flanks. These are of course made the highest of the two, and are usually of the same height nearly as the faces of the bastion or orillon, whereas the parapet of the lower flanks in this construction is seldom or never made higher than the crest of the glacis. Consequently a section through a double flank exactly corresponds, in every respect, with the section of the faussebray system; and the same objections, before urged in treating of that system, apply to a reveted second flank, if placed too near to the parapet of the lower flank.

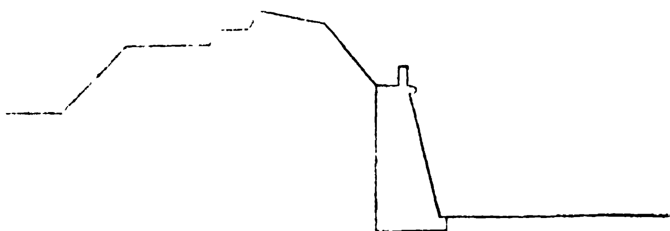
In fortresses constructed with orillons, the reverse of these works is often chosen as a good position for sallyports leading

either from the interior of the bastions into the main ditch, or into the terreplein of the lower flanks.

Sometimes bastions have been constructed with double flanks, although having either no orillons at all, or very small ones; and in this case the upper flank has sometimes been continued so as to meet the face of the bastion, instead of terminating at some distance from it, in the manner represented in our present figure: and when this construction has been followed, that portion of each face, towards the shoulder of the bastion, which is intercepted by the upper flanks, has generally been made rather lower than the remainder of it.*

In such of the more early modern fortresses, as were not constructed with faussebrays, it was usual to leave a berm of from 5 to 10 feet broad, at the bottom of an unreveted parapet; which berm, being used as a path by the officers on guard in going their rounds, was called THE ROUNDWAY.

The roundway had a thin brick wall on the outside of it, generally not more than three or four feet high, being chiefly intended for the purpose of preventing accidents. Sometimes, however, it was made stronger and higher than usual, and pierced with loopholes for the use of musquetry. The section of a rampart, so constructed, is as follows.



* This construction has been adopted by Coehorn, one of the most celebrated engineers of modern times, in some fronts of the famous fortress of Bergenopzoom.

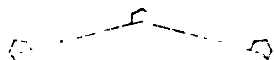
In order to establish a proper communication between the terreplein and the roundway, passages were cut through the parapet in various parts, especially near the salient angles of the bastions; at which angles, small stone turrets were also usually erected, in which sentinels were posted.

These PERMANENT OR STONE SENTRY-BOXES were either made circular or in the form of small polygons, the lower courses being built like corbels, so that the body of each sentry-box projected beyond the general line of the scarp revetment, and its walls were loopholed, in order to enable the sentinel to make his observations in all directions.

Roundways and stone sentry-boxes have long been generally disapproved. Small guards posted in the covered way and outworks provide more effectually against a surprise than the former; and the latter being usually conspicuous and ornamental objects, and placed on fixed points, so as to make known the positions of the principal works, served only as marks for the enemy's artillery, to the prejudice of the defence.

I shall next proceed to describe what is called the TOWER BASTION SYSTEM OF FORTIFICATION, which was introduced by Vauban, in some of the last fortresses constructed by him

Draw two right lines, representing curtains, and draw three very small bastions at their extremities, to show the TOWER BASTIONS.



The nature of such works may be easily understood from their name, they being merely large towers built in the form of bastions. The lower apartments of these towers are strongly arched over, with such a thickness of masonry and rubbish as to prevent bombs or shells from penetrating. At the top is a platform or terreplein nearly level, having a parapet of the usual height, but formed of

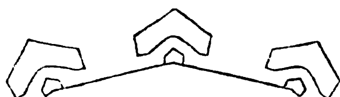
brick in order to save room, the thickness being about 8 feet. A loopholed brick wall, about 3 feet thick only, inclosed the gorge, the outline of which is, however, not yet correctly represented. It is not my intention to describe the construction of these works minutely. Suffice it to say that the flanks were made perpendicular to the curtains, and the salient angles always right angles; and the size of the towers was such as to admit of three guns being mounted in each face, and of two guns being mounted in that part of each flank, which projected beyond the scarp line of the curtain.

Such is nearly the outline of the main inclosure of the system now under consideration, which so far differs very little, excepting in the greater magnitude and form of its towers, from the plan usually followed in ancient times before the invention of gunpowder.

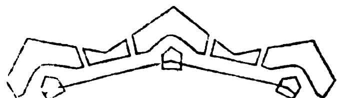
In order to render the tower bastion system more conformable to the rules of modern fortification, an exterior line of works was therefore added, consisting of common bastions and tenails, both of the usual size.

These bastions being separated from the main inclosure by a ditch, and not being connected by curtains, are called DETACHED BASTIONS.

In front of each of the three tower bastions represented in your figure, draw a detached bastion, the faces of which are supposed to be directed upon the angles of the flank of the main inclosure.

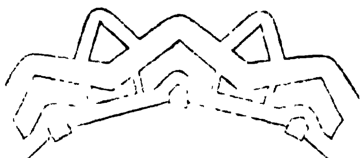


Between each of these detached bastions draw tenails; and finish your tower bastions, the form of which is not yet complete, by producing their flanks a little in rear of the curtains, and drawing the gorge of each, perpendicular to its capital.



The curtains produced, until they meet each other in front of the gorges of the tower bastions, as represented in our figure, constitute the interior sides of the polygon, in this construction. Its exterior sides, if required, would be denoted by right lines, drawn so as to connect the points of the detached bastions.

Beyond the detached bastions and tenails, there may be a chain of ravelins, or other outworks, a covered way, and glacis, all of which may be constructed in the usual manner.



Draw therefore a couple of ravelins in front of your tenails: and draw also the counterscarp in front of your detached bastions and ravelins; rubbing out, at the same time, those parts of the interior sides of the polygon, which become superfluous after the tower bastions are completed.

Our figure, in its present state, represents Vauban's second system of fortification. In this he fortified outwards, that is to say, he drew the interior sides of his polygon first, making them each 256 yards long. Then he produced the radii to the distance of 84 yards, in front of the point of each of his towers, by which means he found the position of the salient angles of his detached bastions. In consequence of this construction, the exterior side was not by any means fixed, but varied according to the nature of the polygon; so that in the hexagon, for instance, it was about 357 yards long, and in other polygons of a greater number of sides it became shorter than the above dimension; its length always diminishing in proportion to the magnitude of the polygon.

In his third system, which is also constructed with tower bastions, instead of forming the curtain in one continued right line, it is laid out in the form of a kind of front of fortification, but with so very short a perpendicular, that flanks of

about 12 or 13 yards only are thereby obtained. This is the only apparent variation between the outline of the third system of Vauban, and that of his second system above described, as they appear to the eye on a hasty inspection. Their dimensions, however, and construction, when they come to be more accurately examined, are very different. In the third system he made his tower bastions a little larger than in the former: and he fortified inwards, making the exterior side in all cases equal to 384 yards, the perpendicular equal to one sixth of the exterior side, and the faces of the detached bastions 128 yards long. Consequently all the works are on a considerably greater scale, than those of his second system.

In both systems communications are constructed near the flanks of the towers, leading from the body of the place to the detached bastions: whilst the latter works may communicate with the adjoining extremities of each tenail, by means of sallyports pierced in their flanks. There is also a direct communication to the tenails from the curtains of the main inclosure, in the usual manner. And it is to be remarked, that the ditch of the body of the place is only about half the width of that which is in front of the detached bastions and tenails, so that the latter is in reality the main ditch of the fortress.

Notwithstanding the great reputation of the author of the tower bastion system of fortification, and although it was his last, and probably his favourite mode of construction, being the only one in which he so materially differs from former engineers as to establish any claim for originality; yet it is to be remarked that this system has not, in any subsequent period, either been imitated or generally approved.*

* Mr. Bousmard (in his *Essai Général de Fortification*) is, however, an advocate for Vauban's tower bastions.

I shall now proceed to describe the methods which have been used in strengthening works of fortification by means of retrenchments.

One mode of retrenching a full bastion, namely by a defensible cavalier, has already been explained: the other methods commonly adopted for the same purpose are as follows.

Sometimes a bastion may be retrenched by a work laid out in the form of a simple tenail.

In order to represent this kind of retrenchment, draw two bastions connected by a curtain, which being done, from the shoulders of your left bastion draw two right lines meeting each other in the capital of that work, so as to form a reentering angle (*See the left bastion of the following figure*).



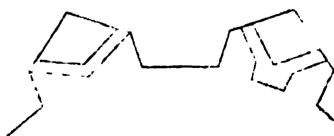
Sometimes the retrenchment of a bastion may be constructed in the form of a small front of fortification.

Draw a retrenchment in your right bastion, in this last mentioned form; and let its extremities terminate near the shoulders of that bastion.



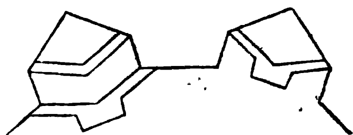
These retrenchments have ditches, and sometimes a covered way; and they are supposed to have a small command, usually not exceeding 2 or 3 feet, over the body of the place.

Complete the form of the ditches of the retrenchments of both your bastions, by drawing their counterscarps.



When the retrenchment of a bastion is formed by a small front of fortification, it is sometimes placed in a more retired situation

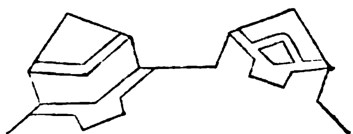
than is represented in our present figure. For example, the extremities of the retrenchment may terminate at or near the angles of the flank.



To exemplify this method, draw an additional retrenchment behind your left bastion, in the form of a small front of fortification; and let the extremities of it terminate in rear of the angles of the flank, and at a short distance from them, upon the adjoining curtains. Represent also the ditch of this new work.

The left bastion of your present figure is now protected by a double line of retrenchment.

Retrenchments may also have small outworks in front of them, either constructed in the form of ravelins or otherwise.



Add a small ravelin to the retrenchment of your right bastion; and represent also the ditch of this additional work.

From the above examples, it will readily be understood, that there may be many methods of retrenching a spacious bastion. To give some notion of the dimensions of such retrenchments, I shall remark, that if we suppose the two original bastions of our figure to represent part of a regular octagon fortified according to Vauban's first system, the small front of fortification, which retrenches the right bastion, may have an exterior side of about 160 yards; and that, which is in rear of the left bastion, would be about 140 yards long, if it terminated exactly on the angles of the flank, but by gaining a little upon the adjoining curtains it becomes so much the longer.

REMARK.

For a reason stated in a former chapter, the parapets of the flanks of such short fronts of fortification, as those above described,

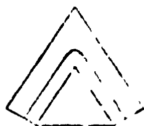
could not be able to see into the whole of the ditch, with proper effect. It is however to be observed, lest there should be any misconception of what was there advanced, that in case an enemy should attempt to take the retrenchment by escalade, although he might not be exposed to any danger from musquet shot, whilst standing in the bottom of the ditch; yet in proportion as he ascended above that level, in the operation of scaling, he would gradually come under the fire of the flanks, before he reached the summit of the wall. And under this consideration, it will be evident, that imperfect flanking defences are not in all cases to be absolutely rejected.

In order to explain the mode of retrenching a ravelin, you will first draw a work of that description, with a break at the gorge in the usual form.

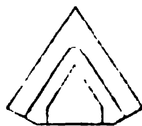
In rear of the faces of the ravelin, and parallel to them, at any convenient distance, draw two lines, meeting in a salient angle, to represent the faces of the retrenchment.



Draw also the ditch of this work, in the usual manner.



You will next draw two small flanks to your retrenchment, and rub out those parts of the faces of it, which will become superfluous after the flanks are drawn.



The representation of a retrenched ravelin, in its most approved form, is now complete.

The retrenchment of the ravelin, not being intended to act as a cavalier, has usually a command over that work of about 2 or 3 feet only; and in order that both of them may be properly commanded by the body of the place, a retrenched ravelin is generally made 1 or 2 feet lower than an unretrenched one.

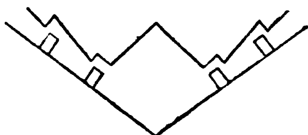
The scarp line of the faces of the retrenchment cannot conve-

niently be laid out, at much less than a distance of about 20 yards from the interior crest of the parapet of the ravelin, for the same reason, which was before stated, in treating of defensible cavaliers.

The top of the scarp revetment of the retrenchment may be on the same level nearly with its own terreplein; and the height of masonry is usually less by 8 or 10 feet, than that of the scarp revetment of the ravelin, when the latter has a respectable profile. Consequently the ditch of the retrenchment is laid out on a higher level than that of the ravelin, having a sudden fall, or drop, as it is called, at each extremity. It is usually made about 11 yards wide, and its counterscarp is reveted. The side of each drop is also reveted, as an additional obstacle to prevent an enemy from penetrating, by the ditch of the retrenchment, into the terreplein of the advanced part of the ravelin.

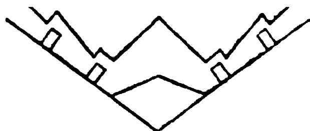
It is also usual to retrench the reentering places of arms of the covered way.

Draw a figure to represent a reentering place of arms, with two adjoining branches of the covered way, marking a couple of traverses in each.

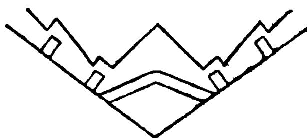


The retrenchment of the reentering places of arms usually consists of two faces, forming an obtuse angle.

Draw two right lines accordingly, to represent the faces of a retrenchment of the above description, placing them in such a situation, as not to interfere with the retired traverses of the adjoining branches.



This being done, complete the form of your retrenchment by representing its ditch.



In proportion as the salient angle of this kind of retrenchment is more obtuse, the less exposed will it be to the enemy's enfilading or reverse fire; but at the same time the flanking defences, which it might derive from the adjoining bastion and ravelin, particularly from the former, will become so much the more oblique, and consequently less effectual.

The retrenchment of the reentering place of arms has usually a command of about 2 feet over the crest of the glacis. Its revetment may be from 15 to 18 feet high; and its ditch, which is usually 6 or 7 yards broad, does not in general exceed 12 feet in depth. The parapet is made only 12 or 13 feet thick, except at the inward extremity of each face, adjoining to the counterscarp; and there, the outline of the interior crest of it is not made parallel to the exterior crest or scarp line, but has a return backwards, in the form of a small flank, nearly parallel to the capital of the work; by which means greater strength is gained, in what are supposed to be the most exposed parts.

REMARK.

Any interior work or retrenchment, which is so constructed, that an enemy cannot conveniently attack it, until he has previously made himself master of the exterior work, which it is intended to support, is called A KEEP, because it affords a safe retreat to the garrison of the principal work, in case of necessity. Thus, for example, in ancient castles of any considerable extent, there usually was a high tower, or a more commanding but smaller castle, erected within the central area, so denominated; and in modern fortification, as the retrenchments in the ravelin and covered way come precisely under the above definition, the former is also sometimes called THE KEEP IN THE RAVELIN, and the latter THE KEEP IN THE COVERED WAY.

We have hitherto supposed all our retrenchments or interior

defences to be reveted with masonry, in a permanent manner, and to have a proper terreplein with good earthen parapets, as also ditches and reveted counterscarps, and, in certain cases, even a small covered way in front of them.

Sometimes, however, for the sake of economy, and sometimes from want of time, as for instance when a fortress is either actually attacked, or liable to a sudden assault, the works have often been retrenched in a less substantial manner.

For example, the retrenchments in the ravelin and covered way have sometimes simply consisted in brick walls, from 1½ to 3 feet thick, pierced with loopholes for musquetry at convenient intervals, and having a small ditch in front of them of about 6 or 7 feet deep, and 4 or 5 yards wide.

In such retrenchments, as they are quite incapable of resisting cannon shot, the wall should be covered as much as possible from the besiegers' batteries, which are supposed to be established near the crest of the glacis. This is done by making the top of the masonry considerably lower than the parapet of the ravelin. It is however proper, that it should at least be of such a height, that when the remainder of the ravelin is taken, and the enemy are established on the terreplein of that work, the troops within the retrenchment may be every where completely screened against musquet shot.

Sometimes, but particularly when the garrison of a place is pressed for time, retrenchments may be made of timber.

This is done by firmly fixing in the ground strong piles, of oak or other hard wood, not less than six inches thick, but the thicker the better, in such a manner as to form a continued line of about 7 or 8 feet high above the level of the interior of the work, which is to be retrenched; a part of these piles being previously notched in such a manner that, when they are put together, there shall be convenient loopholes for musquetry left in them at proper inter-

vals, whilst the remainder of the work forms a solid wooden wall.

A work of solid timber of the above nature is called a stockade, to distinguish it from a common line of palisading, which is usually much weaker.

When A STOCKADE is of very inconsiderable extent, so that it cannot be deemed a proper retrenchment, but merely serves as a small keep near the gorge of a place of arms, ravelin, or other work, to afford means of retreat to the defenders in case of an assault, it is styled a tambour; and the same term is applied, in field fortification, to a similar obstacle, which is often formed in front of a gateway, that is not protected by a ditch and drawbridge in the usual manner.

When nothing is specified to the contrary, A TAMBOUR is always supposed to be formed by means of a stockade, or palisading, or other timber work; but the same term may also with equal propriety be applied to a brick wall, if of very inconsiderable extent, and used for the same purposes, which have just been mentioned.

A tambour may be further secured by a ditch in front of it, with inclined palisades sloping outwards to add to its defence. When composed of stockade work, it may have a half roof towards the rear in the form of an open shed or penthouse; and a trench may be cut behind it, for the purpose of receiving and deadening the effect of grenades, splinters of shells, &c. unless when it is placed so near to the reverse of any work, that the common ditches of the fortress will answer that purpose.

In the full bastions, and in the reentering places of arms, of a place menaced with an attack, a more serviceable retrenchment, than either a brick wall or stockade, may be formed by throwing up earthen works resembling common field works. But for the reason

stated, in treating of earthen ramparts, these must be strengthened by palisades, fraises, or chevaux de frize, in order to secure them against an assault, which will oblige the enemy to have recourse to the more tedious process of forming batteries or mines.

To obviate the disadvantages attending earthen slopes, the scarp and counterscarp of such works may sometimes be retained by means of A TIMBER REVETMENT, the nature of which is as follows.

PILES of about 1 foot square, and of a suitable length, are fixed in the ground to a sufficient depth to insure their stability, and at intervals of about four feet apart; behind which is applied a lining of strong PLANKS, and then the mass of earth is thrown in.

In order to add to the security of the piles, which form the principal strength of a timber revetment, and which in fact bear the whole pressure of earth, it is proper to connect them with other strong pieces, laid horizontally in the mass of earth, which from that circumstance are called LAND TIES. Instead of building a timber revetment perpendicularly, it also conduces to its strength to form it with a certain slope, which, however, should not be greater than about one fourth of the height.

When palisades are used for strengthening works, it is to be remarked, that the larger the scantling of which they are composed the better. Entire trunks, for instance, of well-grown trees, are preferable to every other kind, if the great difficulty and expense of procuring a sufficient quantity of this description did not render it necessary often to be contented with slighter ones. Palisades, formed of large timber, not only offer an almost insurmountable obstacle against men attempting to cut them down by main force, under fire, but they afford effectual protection against musquet shot, and under certain circumstances, it has even been found difficult to make any impression upon them by light field pieces.

By way of distinction, the term stockade is also applied to the superior kind of palisading, which has just been described.

Sometimes palisades have not been fixed in the common manner, but hung in bays, as it is called, which construction is as follows.

Strong posts are first planted firmly in the ground to a sufficient depth; and then cross bars or rails are fixed to them horizontally, near the top and bottom; to which rails the palisades are afterwards connected by means of spikes, so as to hang with their lower ends at some little distance from the ground. This construction, which could only have originated from motives of economy, is the worst that can be imagined: for the palisades thus fixed are usually of a triangular shaped scantling, of too insignificant thickness to resist musquet shot in any part; and in case of an attack upon them by main force, the moment that an enemy succeeds in sawing or breaking off the ends of two rails only, a whole bay of palisading is of course thrown down and rendered useless at once.

These rails are commonly called ribbands. In HANGING PALISADES two ribbands must always be used in each bay; and even in the common STANDING PALISADES, at least when formed of regular scantling, a ribband is usually fixed near the top, at such a height as to form a convenient rest for the soldier's musquet, in firing between the interstices.

Fraises have also a ribband, often fixed to their lower surface near the projecting end of them; whilst their buried ends are attached to another, which from its position is called a sleeper. These cross pieces or RIBBANDS, in both cases, contribute to strength, as well as to regularity, in executing the work.

In strengthening the works of a fortress by means of retrenchments, fascines, sand bags, and gabions, are also employed. The two former materials have been already described. The latter are a kind of baskets made of wicker work, of a cylindrical form,

but open at top and bottom; which being set upright according to any given alinement, and filled with earth, form a good revetment for a parapet, traverse, &c. GABIONS, used for the above purposes, should not be less than 2½ feet exterior diameter: 3 feet is a still better proportion, unless the gabions are placed at a slope, which increases the strength of this as well as of every other kind of revetment. The usual height of gabions is about 3 feet, but they may be made higher in particular cases, if judged necessary.* Casks with one end taken out, so as to receive earth, are often used as gabions, and if sufficiently large they form an equally good revetment.

I shall conclude the subject of retrenchments by observing, that in cities built of stone or brick, in a substantial manner, without any very great proportion of timber, it is proper to oppose an enemy's progress, after a breach is formed in the body of the place, by fortifying the adjoining streets and houses. For this purpose, the doors and windows facing towards the breach are built up or strongly barricaded, and the walls of the houses in that direction are loopholed. Cuts are formed on the terreplein, to the right and left of the breach, and continued from thence to the adjoining houses; and all the streets, by means of which the enemy might penetrate, are secured in the same manner. This being done, and due precautions taken to prevent fire, the fortified houses and cuts will form an obstacle of the most formidable nature against a common assault. Indeed in some countries, in which timber is scarce, and in which it is the fashion to build with very thick

* In carrying on the regular sap in a siege, a much lighter kind of gabion is necessary, than would be desirable in any other case. Sap gabions are accordingly made only 2 feet in diameter, and about 2 feet 9 inches high.

walls and flat roofs,* the public buildings, and even many of the dwelling houses, if defended with proper spirit and vigour, may be deemed almost impregnable against an attack by infantry alone.

CHAP. XVIII.

OF BOMBPROOFS, CASEMATES, POWDER MAGAZINES, CRENNELED COUNTERSCARP GALLERIES, GALLERIES OF COMMUNICATION, AND CASEMATED CAPONIERS.

Any building, which is formed of such solid materials and dimensions, as to be capable of resisting the force of bombs or shells, falling upon it, is called A BOMBPROOF.

The usual mode of constructing bombproofs is to form apartments arched over at top, of a moderate width, that is to say, not exceeding about 18 or 20 feet at the utmost, but of a more considerable length, the thickness of the arch, or of the masonry at top, never being made less than 3 feet, in its weakest part.

Powder magazines should always be bombproof; in addition to which, it is in all fortresses proper, but in small fortresses absolutely and indispensably necessary, that the principal hospitals, barracks, and storehouses, should be built in the same manner; otherwise the garrison and stores, being continually exposed to the

* The houses in Malta are constructed in this manner, as also those of Buenos Ayres. Those of Saragossa are less favourably formed for defence, not having flat roofs, and being more combustible; and yet in the two late famous sieges of that place by the French, the houses offered by far a greater obstacle to the enemy, than the fortifications.

enemy's shells night and day without intermission, no effectual resistance for any length of time could be expected.*

Bombproof buildings may either be insulated, or placed at some distance from the fortifications, or they may be constructed under the ramparts of a fortress, in which latter case they are called CASEMATES.

A rampart provided with casemates, or in other words A CASEMATED RAMPART, as it is usually styled, has no interior slope, the back of it being reveted. The front walls of casemates are formed by the common scarp revetments of the fortress.

Sometimes casemates have embrasures pierced through the front of them, for the use of guns or howitzers; which embrasures, being cut out of the revetment, are of course either arched over or covered with long stones.

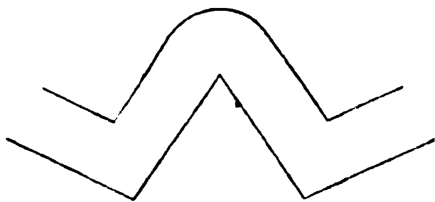
Guns, placed in a casemate, constitute what is called A CASEMATED BATTERY.

Casemated batteries are most essentially necessary for the defence of dead angles and faces, which cannot be seen into by any other means. From hence it follows, that in the bastionary

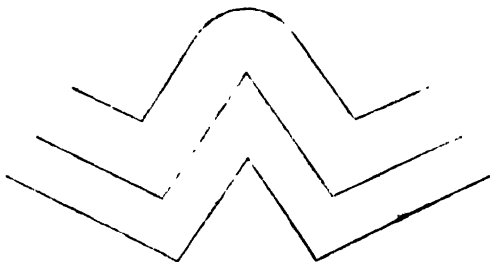
* A small fortress without bombproofs may, for the above reason, be considered absolutely untenable against a vigorous bombardment. In a very large extensive fortress, on the contrary, there must always be some parts, which will not suffer by the effect of the enemy's shells. But as the particular points, against which the besiegers may direct their fire, cannot be foreseen, before an attack actually commences, the greatest confusion and trouble may be occasioned, in the event of a bombardment, by the necessity of removing troops and stores from those situations, which happen to be the most exposed. Consequently, although fewer bombproofs, in proportion to the magnitude of the works, may be necessary in a large fortress, than in a smaller one; still it may be laid down as a rule, that every fortress, however extensive, which is entirely destitute of bombproofs or casemates, must be considered defective.

system of fortification, they may be useful, but in the redan system, they are absolutely indispensable.

Draw part of the outline of a work, constructed according to this last mentioned system, consisting of one redan and two adjoining faces; and complete your figure by representing a ditch in front of it.

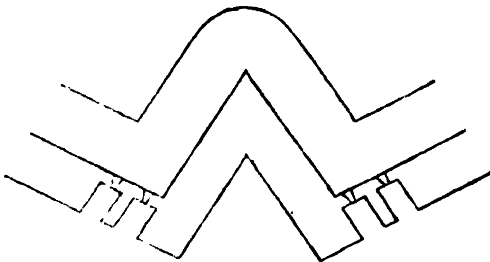


Parallel to the scarp line, and in rear of it, draw another set of lines, to represent the back of a casemated rampart.



In each of the adjoining faces, which flank your redan, draw two casemates of a rectangular form nearly, separated from one another by an intermediate wall or pier. Represent also the thickness of the scarp revetment in front of them, but let them be open in rear.

Draw an embrasure, in the front wall of each casemate, wider in front than in rear.



Each face of your redan is now flanked by a casemated battery of two guns, which, being placed sufficiently low, may either scour the whole of the bottom of the ditch, or nearly the whole of it;

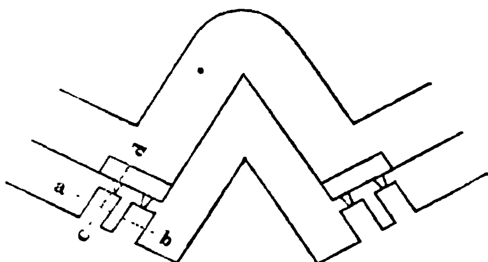
whilst the guns or musquetry from the ramparts above would not be able to see into it, for reasons before explained.

When the embrasures of a casemated battery are placed very low, it is usual to make that part of the ditch, which is immediately in front of them, several feet deeper than the rest of it, in order to prevent the enemy from approaching too close to them.

Any part of a ditch, sunk in this manner, is called a drop, as was before explained.

Draw lines to mark the extent of each drop.

The dotted lines, also added to the figure, are introduced to show the direction in which sections are afterwards to be drawn.



THE DROP is of course a dead part of the ditch, but this circumstance is not prejudicial, the scarp being so much higher there, than at any other part, that it is not favourable for an assault.

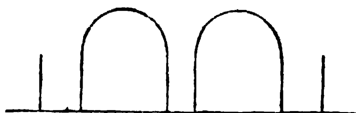
To explain the nature of casemates more fully, we shall next draw the transverse section of two of them, taken across the arches *(in the direction marked* a b, *in our figure).*

Draw first a line to represent the level of the terreplein, under which the casemates are constructed.

Parallel to which and below it, draw a second line, at any convenient distance, to represent the floor of the two casemates.

Mark points on the last drawn line, to show the thickness of the walls, and the breadth of the two casemates, from which points raise perpendiculars of equal length, to show the height of the walls, from the floor of the casemates to the spring of the arches

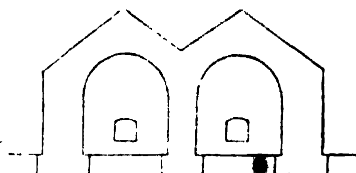
Then draw two arches, which you may make semicircular, it being understood, however, that this form is not always used.



Over each arch, draw a ridge like that of a common roof, to show the manner in which the masonry of casemates is usually finished at top.

Draw also the foundations of the walls of your casemates, giving them an offset on each side, in the usual manner.

And in the center of each casemate, a little above the floor, draw a small figure arched at top, so as somewhat to resemble the casemate itself in form, but on about one fifth part of the scale only, and with a segment arch rather flat, instead of a semicircle.



The transverse section of your two casemates (*on the line* a b) is now complete, the small figures, which were last drawn, being supposed to represent the CASEMATED EMBRASURES seen in elevation.

When casemates are built for the purpose of accommodating troops, it is desirable that they should not be less than 16 feet wide, in order to afford room for a double row of soldiers' beds, with a passage in the middle. 18 feet will, of course, be still more convenient. When intended chiefly as batteries, a width of 14 feet is sufficient.

In a range of casemates, or other bombproofs, the same terms apply, which are used in speaking of a bridge, or any other work composed of a series of arches, the intermediate walls being called PIERS, and the end walls the ABUTMENTS.

Bombproofs are sometimes but not often constructed with two stories. When there is only one story, the piers are seldom made more than 6 or 7 feet high, measuring from the level of the floor to the spring of the arches, and they are scarcely ever made less than 3 feet, or more than 6 feet thick.

When the thickness of the piers of a range of bombproofs or casemates is inconsiderable, it is usual to make the abutments much stronger than the piers; but when the piers themselves are thick, or when the abutments terminate on a terreplein or mass of earth, this precaution is less necessary.

In building casemates, after the roof is formed with masonry or brick work, the whole surface of it is covered with water-proof cement, and sometimes for greater security the ridges and gutters are leaded. In the latter, small drains are formed with a proper slope, in order to receive and carry off the rain water, which soaks through from the terreplein. Then a couple of courses of dry bricks are placed over the remaining parts of the roof, in the lowest of which the bricks are laid at such intervals apart, as to form narrow channels, leading perpendicularly down the slope to the main drains before mentioned, with which they communicate. This being done, a quantity of shingle or pebbles is next applied, the largest of which are placed at bottom. These are afterwards covered with a layer of clay, over which common earth or rubbish is thrown in, until the terreplein is raised to its proper level.* In

* The clay is intended to prevent the particles of common earth from sinking into the intervals between the shingle and dry bricks, which in course of time might fill them up, and impede the water from running down along the slope of the roof into the gutter.

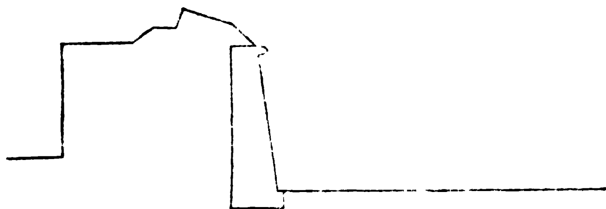
The mode, above described, has been very generally adopted in our casemates in this country. In certain cases, however, the dry bricks, as being of too porous a nature, have been omitted. shingle only being used immediately over the cement; and some engineers are of opinion that this last method is the best.

It may be remarked, that notwithstanding the care used in the con-

short, unless the greatest care is taken, in northern climates, the casemates must necessarily be damp; and in this case, the expense laid out in their construction will be, in a great measure, thrown away, for they will neither afford wholesome quarters for troops, nor will they even be fit for the reception of dry stores. Sometimes therefore, in addition to the precautions before mentioned, particularly in small works, the terreplein is paved with flag stones, or covered with cement, to prevent the rain water from penetrating below the surface.

To complete our explanation of the nature of casemates, we shall next draw a longitudinal section, supposed to be taken through the middle of one of those represented in a former figure, *on the line,* c d. (*See page* 365.)

Draw the section of a reveted rampart complete, but without any counterfort; and also without the interior slope, in lieu of which you will substitute a perpendicular, to show the back of the proposed casemate.



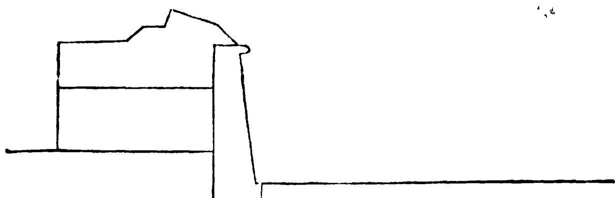
Draw a horizontal line extending as far as the back of the

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struction of them, there are few or none of our ranges of casemates in England, thoroughly free from damp in every part. The grand object of rendering them wholesome and fit for the reception of troops and stores has however been gained, which without the above precautions could not possibly have been effected in so moist a climate. A much more certain and effectual mode would be to cover the roofs of casemates entirely with lead, before the rubbish is laid on; but the expense is an objection. From St. Paul's remarks upon casemates, it may be inferred, that those which have been constructed by the French engineers are much inferior to ours.

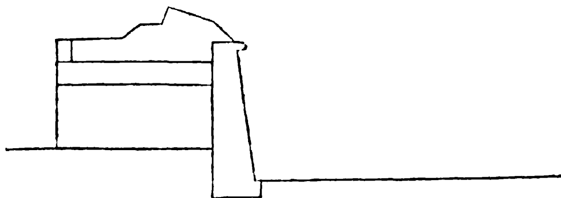
scarp revetment, in order to represent the floor of the casemate, which in most cases is placed some feet lower than the original ground line.

Draw another line parallel to it, at the proper height above it, to represent the under part of the arch.



Above your last drawn line, draw a third line also parallel, to show the ridge or top of the masonry; which being done, the space, comprehended between these two last drawn parallels, will represent the thickness of masonry over the crown of the arch.

The rubbish, laid upon the arch of the casemate, will of course require a wall to retain it in rear. You will therefore draw a small retaining wall accordingly.

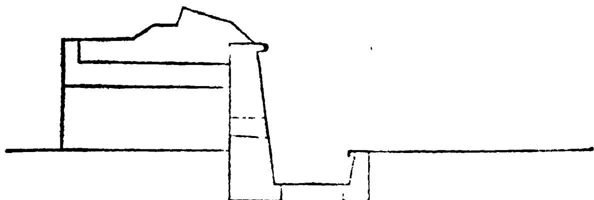


The casemate, represented in our present figure, being considerably higher than the general level of the ditch, would not require any drop.

In order, however, to show this last-mentioned construction, you will alter your figure so as to represent a casemate with a drop in front of it, which is supposed to be excavated beneath the general level of the ditch of the casemated rampart: and draw a small revetment for the counterscarp side of your drop.

Draw also a couple of lines across the scarp revetment, a little

above the floor of the casemate, in order to represent the casemated embrasure.



In former times the arches of bombproofs were generally made semicircular, but in some cases, segment arches of from 90 to 120 degrees were used. Of late, however, parabolic arches have often had a preference given to them in the British service, the rise of which has usually been made equal to half their span. All the new casemates at Dover have been constructed in this manner.

In a range of bombproofs or casemates, doors or passages of communication are usually made in every pier, from one end to the other, in addition to which small air-holes are also frequently cut through them for the purpose of ventilation. When there is no embrasure for cannon in the front wall of a casemate, one or more loop-holes are usually, but not always, cut in it, for the same purpose. Vertical air-holes are likewise sometimes cut through the arches of casemates, which terminate at top upon the terreplein. There they are usually made very narrow, in order to prevent shells from falling into them, but they may be much wider at bottom. These holes not only create a circulation of air, but are useful in carrying off the smoke when the guns are fired, which is a very great impediment to the service of casemated batteries.

In casemates intended for the use of troops, fire-places are made, the flues of which are usually carried up through some part of the parapet; and such casemates are always inclosed in rear by a wall of moderate thickness, like that of a common dwelling house,

having a door, and two windows, one on each side of it, and sometimes a small additional window over it.*

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* The dimensions of some casemates, which have actually been executed, are as follows.

1st. The casemates in the left demibastion of Fort Ricasoli in Malta, are 35 feet 8 inches long, by 20 feet 6 inches wide. The piers are 7 feet thick, with two doors of communication in each, and 5 feet 6 inches high, up to the spring of the arches, which are semicircular. There are embrasures at the height of 2 feet 1 inches above the floor, the interior dimensions of which are 2 feet 3 inches in width by 3 feet in height, their exterior dimensions being 7 feet in width by 4 feet 3 inches in height. The thickness of the scarp wall, through which they are pierced, is 6 feet 8 inches. An air-hole, nearly vertical, is cut in the arch of each casemate, towards the front of it, the dimensions of which are 1 foot 9 inches by 2 feet at top, and 1 feet 6 inches by 5 feet at bottom. These casemates are open in rear, with the exception of a thin wall raised 3 or 4 feet only above the floor. Seven of them contained heavy guns, which, for the sake of experiment, were fired five or six times as quick as possible, and the smoke was found to go off pretty freely.

2d. The casemates in the King's and Orange bastions at Gibraltar have, by long experience, been found good healthy quarters for troops. They are all about 16 feet wide, and of the same height up to the crown of the arches, which are semicircular. The piers are about 5 feet thick, with a door of communication in each. The King's bastion casemates are about 40 feet long, and have no openings in the scarp wall in front, nor any air-holes to produce a thorough draft. The Orange bastion casemates are about 90 or 100 feet long, each having two narrow loop-holes in front towards the bay, and three vertical air-holes cut in the arch, which at top are only about 4 or 5 inches wide.

3d. The casemates in the new counterguard at Gibraltar are 16 feet wide, and of various lengths according to the width of the rampart, which is irregular. They are about 6 feet high to the spring of the arches, which are segments of 90 degrees. They have embrasures in front, and a door of communication in each pier.

In some new casemates, which I am informed have lately been constructed at Gibraltar, the width is 18 feet, which may be considered a more convenient dimension for the accommodation of troops.

4th. The casemates at Cumberland Fort near Portsmouth have been inhabited for many years. They are each 38 feet long by 14 feet wide. The piers are 5 feet thick, with two doors of communication in each, and

POWDER MAGAZINES are of two kinds, large and small: the larger serving as the principal stores of that article, are often placed in retired situations; whilst the smaller ones, usually styled expense magazines, serve for the daily expenditure of the garrison, and are therefore distributed in various parts near the principal works and batteries.

Vauban usually made his principal powder magazines, each 64

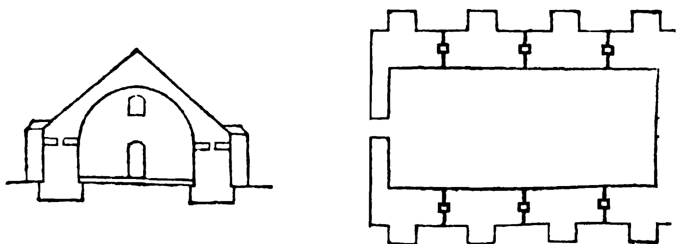
5 feet high up to the spring of the arches, which are segments of 120 degrees, nearly, their rise being 4 feet. In each casemate there is a fire-place, and either an embrasure or a loop-hole in front. The average depth of the crown of the arch below the level of the terreplein is about 7 feet 6 inches. The new casemates, lately constructed at Southsea Castle, have also arches of 120 degrees.

5th. In the casemated cavalier near the left of Chatham Lines, the soldiers' casemates are 61 feet long by 17 feet wide. They are two stories high. The height of the lower story is 10 feet below the joists, which support the wooden floor above it. The height of the upper story is 11 feet from the floor to the crown of the bombproof arches, which are semi-circular. The piers are 4 feet thick, with one door of communication cut through each of them in the upper story, and three air-holes in the lower one. The abutments are about 9 feet thick. The front and end walls of the lower story are sunk in the terreplein of the lines. In both stories are fire-places, and the upper rooms have loop-holes in front, one on each side of the fire-place. A gallery of wood, supported by brick piers, runs along the whole extent of the lower rooms, the top of which being secured by a proper railing, serves as a corridor for the upper story, and is ascended by a flight of steps at each end. A gallery of the above description, or rather one arched over at top, for greater security, is very useful in all casemates built with two stories, for it not only affords the most convenient mode of communicating with the upper story, but serves also as a place of parade for the men in bad weather.

6th. In the fortifications constructed on the Western Heights at Dover, the principal casemates are 77 feet long by 18 feet wide. The piers are 4 feet 1 inch thick, with one door of communication in each, and 8 feet high, up to the spring of the arches, which are parabolical, and have a rise equal to half their span. There are three fire-places in each casemate, and one embrasure in front.

The whole of the above described casemates, excepting those of Fort Ricasoli, are inclosed in rear by a back wall, having a door and windows.

feet long, by 26 feet 8 inches wide, in the clear; the whole being covered by one large semicircular arch. The side walls or piers were 8 feet 6 inches thick; and their interior height was about 6 feet 6 inches above the level of the wooden floor. The end or gable walls were 4 feet 3 inches thick, in each of which was a small window near the level of the crown of the arch. The door of the magazine was also placed at one end. Each pier was strengthened by 4 buttresses or exterior counterforts, about 6 feet 4 inches wide, projecting 4 feet 3 inches beyond the rest of the wall, and placed at intervals of 16 feet apart from center to center. In all the spaces between the adjoining counterforts were air-holes, cut in the side walls, about 3 or 4 inches wide and 18 inches high, not carried on in one continued straight line, but winding to the right and left round a solid die in the center of the wall. The arch was 3 feet 2½ inches thick, above which a ridge was formed, so proportioned, that the total depth of masonry over the crown of the arch was about 8 feet 6 inches, whilst the angle formed by the two sloping sides of the roof, was obtuse in a very small degree. The foundations of the walls, and buttresses, were greatly increased at bottom by means of offsets, in the usual manner. For further explanation, a figure is annexed, in which the plan and section of a magazine, so constructed, are represented in outline. In the section, which is supposed to be taken through the center of one of the air-holes, a door and window and two buttresses are seen in elevation.



Vauban's powder magazines, as above described, were calcu-

lated to contain about 1050 barrels, piled in tiers of three barrels each in height, and by increasing the number of tiers, which may be done to a certain extent, the quantity of gunpowder may be increased in proportion.

In our powder magazines in the British dominions, the arches have never been made so wide as the above; and therefore, whenever a considerable interior capacity was required, the body of the building has generally been formed of two or more arches, connected together by intermediate doors or passages left in the piers.*

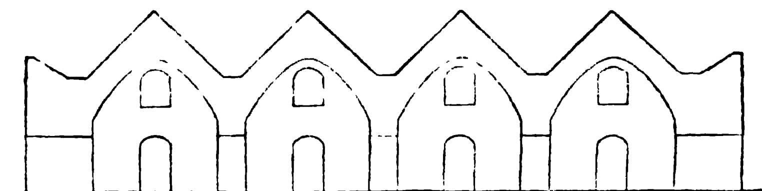
For example, in Upnor magazine, near Chatham, there are four arches, each 88 feet long, by 19 feet wide, in the clear, with piers 4 feet thick, abutments of 10 feet, and end walls equal to the piers in thickness. The height from the level of the floor to the spring of the arches is 9 feet 6 inches, and the latter, which are of the form called catenarian,† have a rise equal to half their span, and are 3 feet thick. The total depth of masonry at the crown of the arch is 7 feet. In every pier there are five interior

* In two powder magazines of equal length and interior capacity, and whose arches are of equal thickness, that which is formed with one very wide arch, is weaker than another formed of two smaller arches, because the strength of an arch, like that of a beam of timber, is diminished in proportion to the distance between the piers which support it. Vauban's plan was therefore explained, not as being a good model to follow in practice, the arch being certainly too wide, but from the circumstance, that experience has repeatedly proved it to be bombproof.

† When a chain is suspended between any two fixed points, it forms a peculiar curve, the chord or span of which may be made to bear any given proportion to the height, by increasing or diminishing the length of the chain. The curve, thus found, is called a CATENARIAN CURVE, which, on comparison, will be found to differ very little from a regular parabola of the same span and height.

doors or passages of communication arched at top, each 5 feet wide and about 7 feet high. Every division of the magazine has one door and window at each end, besides which there is one door in the center of each of the abutments or side walls. There are 20 air-holes in the body of the magazine, 8 of which are pierced in the end walls: besides which there are 16 air-holes leading from the outside of the building below the floor.

The roof is formed of paving tiles laid in common mortar upon the masonry of the ridges, the gutters only being leaded. This powder magazine will hold conveniently about 10,000 barrels, piled in tiers of nine barrels high.* The section of it is as follows.



* Powder magazines are usually divided into certain spaces called bays, by wooden posts or uprights, connected together at top and bottom by open frame-work. A bay, 17 feet 0 inches long by 5 feet 6 inches wide, and 11 feet 2 inches high, will hold 312 common barrels, each containing 90lbs. of loose powder, piled nine high, in alternate courses of twelve and eleven barrels each, placed side to side; the pile being three barrels wide, which, in this direction, are laid end to end. A bay of the same length and height, but about 6 inches wider, will hold 1295 quarter barrels of musquet ball cartridges, containing 500 rounds each, and piled fourteen barrels high, in courses of nineteen and eighteen barrels alternately laid side to side, the pile being five barrels wide. In Upnor magazine there are two bays in the width of every arch, so that passages are left between the parallel bays, as also between each bay and the piers or abutments. Transverse passages are also left, one in the center and one at each end of the magazine, which has 32 bays in all. Some of them are, however, rather larger than the above specified dimensions. Small moveable capstans, placed under the crown of each arch, are used for raising and lowering the

Sometimes powder magazines have been formed with GROINED ARCHES, that is to say with two sets of arches, of equal height or nearly so, intersecting each other at right angles. In this method there is some saving of materials, and a greater interior space may be gained, because instead of intermediate pier walls, extending in a continued line from one end of the magazine to the other, as in the former construction, there are only small pillars of about 4 or 5 feet square at the utmost, which may be placed at considerable intervals apart, and from which the groined arches spring in contrary directions. This construction has, however, been seldom used, being less simple and weaker than the former mode, besides which the formation of the arches and roof is much more troublesome.*

barrels. The construction of Upnor powder magazine has, in general, been very highly approved, it being both dry and commodious.

Barrels, containing gunpowder or cartridges, are seldom piled higher than the above-mentioned height, and when so piled, they require very strong uprights to resist their lateral pressure.

* The ridges, &c. of the roof of a powder magazine, constructed with groined arches, are so disposed, that four gutters must necessarily intersect each other, in contrary directions, over every square pillar, in consequence of which, deep hollows are formed in various parts of the roof, from whence the rain water cannot be carried off, except by vertical drains leading down into the body of the magazine.

The powder magazine at Tipner Point, near Portsmouth, is built with groined arches. Its dimensions between the four exterior walls are 87 feet by 61 feet 6 inches in the clear. There are three main arches, of a parabolic form, in the width of the building, each 17 feet 6 inches wide, springing at the height of 8 feet 9 inches from the floor, and having a rise equal to half their span. There are two ranges of pillars in the width of the building, each 4 feet 6 inches square, which in one direction support the main arches above described. In the contrary direction, they support the arches that form the groins, which are equal to the former in height, but of a much smaller span, the center arch being only 5 feet wide, and the others 7 feet. The number of these transverse arches is seven in all, in the length of the building, the first and last of which terminate, however, not on square

With respect to the roofs of powder magazines, and other bomb-proofs, which are not covered at top with some feet of rubbish, like those of casemates, it is prudent, on that account, to add to the thickness of masonry, in order to make them equally secure against shells;* but the same precautions against damp are unnecessary, for the common slates or tiling, &c. used in dwelling houses, are quite sufficient, provided that the ridges and gutters are leaded. Much however depends upon the pitch of the roof, which ought to be rather steep than otherwise; the low pitch, recommended by some architects for the sake of beauty, being unfit for northern climates.† Sometimes, as in Vauban's

pillars, like the others, but on abutment piers 4 feet 6 inches thick and 6 feet 6 inches long, engaged in the end walls of the magazine, which are 5 feet thick. The thickness of the side walls is 6 feet. The dimensions of the walls, and pillars, below the level of the floor, are greatly increased by means of offsets. No ridges of masonry were formed above the arches, but the whole edifice was covered with a wooden roof, and then sheeted over with copper.

* A shell, falling on the ground, seldom penetrates more than 3 or 4 feet in stiff earth. Consequently it will be evident, that when a casemate is covered with several feet of earth or rubbish, above the arch, the shock of a shell striking the roof, must be greatly deadened before it can act upon the masonry. But if no earth were used, the effect of shells, falling repeatedly upon the same part of the roof must be similar to that of shot, fired from a breaching battery against a revetment; that is to say, a considerable number of them might, at first, strike the masonry without materially injuring it, but in the end they would force it in. No bombproofs, excepting those which are covered with some feet of earth at top, would therefore, strictly speaking, deserve that title; if it were practicable to direct the flight of shells from a mortar, with the same accuracy, wherewith balls may be fired from a cannon. Fortunately, however, for the security of such buildings, this is absolutely impossible.

† Of two powder magazines, built at Plymouth, nearly at the same time, and with the same materials, roofs being formed over the arch of each, of good timber covered with patent slating, but of which the one had rather a steeper pitch than the other; the former was always dry and in good

magazines, timbers are applied beneath the tiles; but this is quite superfluous, when the masonry is itself formed with a proper ridge.

Powder magazines are usually provided with double doors and window shutters, which are made of thick materials, and covered with copper. The winding air-holes, before mentioned, are also covered, both inside and out, with copper plates, having a great number of small holes perforated in them. And as an additional security to powder magazines of any importance, an inclosing brick wall, 10 or 11 feet high, is usually built round them, at the distance of about twelve feet. No iron or steel are ever permitted in the construction of powder magazines, these metals being liable to strike fire. The floors are formed of strong planks, with joists below them, which are supported by low brick walls or piers to keep them dry; and care is always taken to produce a proper ventilation below the flooring.

Formerly the gunpowder of fortresses was generally placed in towers or casemates, near or under the ramparts of the main inclosure. But it being found that, in cases of explosion, magazines, so situated, occasioned practicable breaches in the body of the place, and thereby rendered the fortress untenable, a rule has since been adopted, either to remove the principal magazines from the vicinity of the ramparts altogether, or to place them in the center of empty bastions, where, if any accident takes place, their destruction will not lay open the fortress to an assault.

preservation, whilst the latter, although the difference in the slope was by no means considerable, was generally damp, and on inspection, it was found that the timbers were beginning to rot; in consequence of which it became necessary to raise it. To the best of my recollection, the pitch of the roof of this defective magazine was equal to one third of the width.

EXPENSE MAGAZINES are similar in construction to the former, being also made bombproof, but much smaller, and consisting of one arch only.

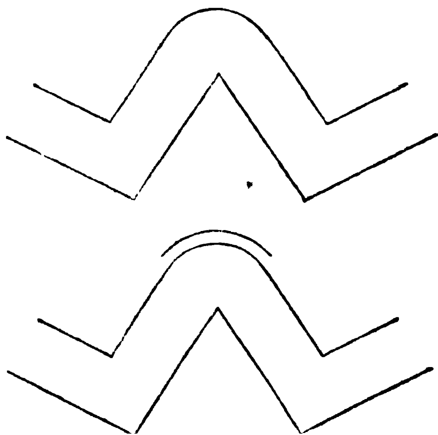
Having sufficiently explained the nature of powder magazines, we shall next treat of galleries.

A gallery in a regular fortress is usually arched over like a casemate, but it is much lower and narrower, and generally longer.

A gallery is often crenneled, or pierced with loop-holes, for the use of musquetry.

Loop-holed galleries are commonly placed at or near the salients of the counterscarp immediately under the covered way, their arches being supported on one side by the counterscarp revetment, and on the other, by a wall built parallel to it.

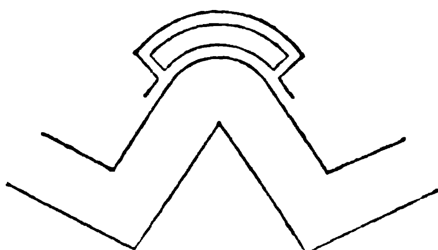
In the first figure which represented the plan of your casemates, rub out every thing except the scarp and counterscarp lines of the work, which was supposed to be built according to the redan system.



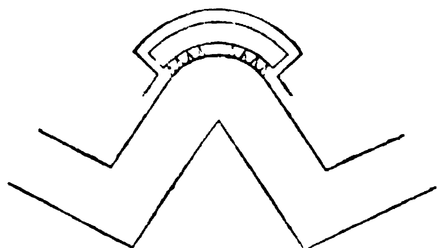
This being done, we shall proceed to draw a crenneled counterscarp gallery in the usual form.

Parallel to your counterscarp line, draw a second line to represent the thickness of the counterscarp revetment, which is to serve for one of the walls or piers of the gallery; and which must therefore be built without counterforts.

Set off a sufficient space to represent the breadth of the gallery, and draw two new lines, also parallel to the former, to show the thickness of the back wall; which being done, draw also the end walls of your gallery.



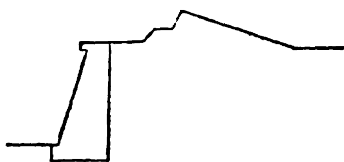
Then draw lines across the counterscarp revetment, to represent the loop-holes of the gallery.



It will now be evident, that an enemy, after penetrating into the ditch, cannot scale the redan, without being exposed to a reverse fire of musquetry from the counterscarp gallery.

Sometimes, but very seldom, casemated batteries have also been placed under the counterscarp.

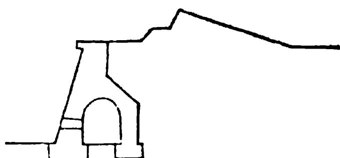
In order to explain more clearly the nature of counterscarp galleries, we shall next draw the section of one, previously representing a ditch, covered way, and glacis, in the usual manner, but omitting the counterfort of the counterscarp revetment.



Behind your counterscarp revetment, and on the same level with the ditch, draw a right line to represent the floor of the gallery, from the extremity of which, raise a perpendicular, to show the interior height of the back wall, and draw a semicircle to represent the arch of the gallery, observing however that this form, although very common, is not always used.

This being done, complete your back wall by drawing the exterior side of it; and draw the roof of your gallery, representing it with one sloping side only, leaning against the counterscarp revetment. Complete also the foundation of the walls of your gallery, giving them offsets in the usual manner.

Lastly, draw two lines across the counterscarp revetment, at any convenient height, to represent a loop-hole.



In addition to the loop-hole, represented in our present figure, it is common in A CRENNELED COUNTERSCARP GALLERY, to form air-holes, also terminating on the counterscarp, but on a much higher level.

These air-holes are usually formed in the proportion of one to every three loop-holes, and are intended for the purpose of carrying off the smoke in firing, which is exceedingly troublesome. This inconvenience would be effectually obviated, by having a store of cross bows and arrows, in every fortress in which such galleries are common, to be issued when necessary, for the use of the defenders of these galleries, in lieu of the common firelock.

Crenneled galleries for musquetry should not be less than 7½ or 8 feet wide, and they should be at least 8½ feet high to the crown of the arch, otherwise there will not be room for loading and firing conveniently, with the common infantry firelock.*

Counterscarp galleries, such as have been described, are in common use. The principal objection urged against them is, that they do not contribute materially to the defence of a fortress,

* The soldier in returning his ramrod after loading, requires a space of at least 8 feet perpendicular height, to do it freely. Much less would suffice by using constrained attitudes, but it is best not to put men out of their way, without absolute necessity.

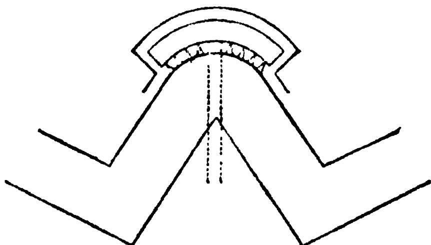
when regularly attacked; for an enemy may penetrate into and either destroy or occupy them by mining, without being exposed to their reverse fire: nor does this process add to the usual labours of a regular siege, because mining is in all cases indispensably necessary, in the attack of fortresses with good reveted counterscarps, in order to form a convenient descent for the besiegers, from the glacis or covered way, to the level of the ditch. And it will be evident, that a counterscarp gallery, thus taken, may be very useful to the enemy in his ulterior operations, although previously of little or no use to the garrison. If however a hasty assault should be ventured by the besiegers, without first making themselves masters of the counterscarp gallery in the above manner, there is no doubt but that the fire of this work would oppose a most formidable obstacle to their success.

Sometimes a counterscarp gallery has a strong door opening into the ditch of the fortress, from whence it communicates with the main inclosure by means of the common sallyports.

Sometimes, for greater security, there is an underground or subterraneous communication, beneath the level of the ditch, which is arched over with a ridge like that of a casemate, and is called a communication gallery.

COMMUNICATION GALLERIES are placed wherever it is judged most convenient. In our present figure, a gallery of this kind might be formed in the direction of the capital of the redan.

Draw two dotted lines to represent the position of your communication gallery accordingly.



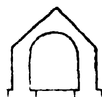
This gallery being much lower than the counterscarp gallery, to

which it leads, it will be necessary to have steps at the end of it. But the manner in which these may be most conveniently placed, will be so easily understood, that we shall not represent any in our present figure.

The section of a communication gallery shall next be drawn.

Draw first a right line to represent the general level of the bottom of the ditch; below which and parallel to it, draw a second line to represent the floor of your communication gallery; and raise perpendiculars of equal length, to show the interior height of the walls up to the spring of the arch. Then draw a semicircle connecting the top of the above perpendiculars, to represent the under part of the arch; and the interior form of your communication gallery will be complete.

Draw the exterior sides of the walls, parallel to their interior sides; drawing also the foundation of each, with offsets in the usual manner. Then draw the top of the gallery, with a ridge like that of a casemate; which being done, your section will be complete.

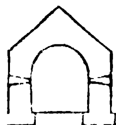


Sometimes communication galleries are not entirely buried under ground like our present one, but only partially so; and in that case, they generally have loop-holes for musquetry, to flank the ditch on each side of them.

A gallery of this last-mentioned description is called A CASEMATED CAPONIER, because it is intended for exactly the same purposes as the common caponier, that is to say, partly as a communication, and partly as a post for musquetry.

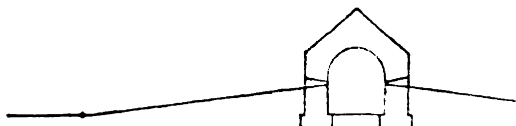
To represent the section of this kind of work, draw a gallery similar to the former, but placing the floor of it on the same level

with the bottom of the ditch; and then add to your figure, by drawing a loop-hole in each of the side walls.



Sometimes a casemated caponier is sunk so much, that the sills of the loop-holes are on the level of the ditch. Sometimes the earth is raised on each side, to the height of the sills, in the form of a small glacis.

Alter your figure, so as to correspond with the last described kind of casemated caponier.



A casemated caponier must be at least 9 feet wide; otherwise it will be impossible for men to fire conveniently, at the same time, in contrary directions: 11 or 12 feet will however be still better. It should, for the same reason, be about 9 feet high, from the floor to the crown of the arch. The floor of a casemated caponier cannot conveniently be sunk more thon 4½ feet; and therefore if we suppose the arch to be 3 feet thick, and formed with a moderately steep ridge, the total height of the masonry cannot be less than 9 or 10 feet above the level of the ditch.*

* Unless there are a couple of steps left as banquettes on each side, and then the caponier may of course be sunk lower; but this will render it less convenient as a communication, by taking from its width.

Sometimes crenneled galleries have been established under the two parapets of a common caponier, with loop-holes on one side of each gallery only, facing outwards. In this case, the parapets of the caponier do not terminate in the form of glacis, but have small ditches in front of them, the scarps of which are formed by the exterior walls of the galleries. This construction constitutes what is called a double casemated caponier.

Galleries and casemated caponiers, not being usually intended as a residence for troops, are seldom roofed with the same care and precautions bestowed upon casemates. It may, however, be observed, that with a view of preventing damp to a certain degree, the exterior sides of the walls, as well as the roofs of subterraneous galleries, are often coated with a casing of dry stones, one or two feet thick, applied between them and the mass of earth in which they are formed. When this is done, the water, which otherwise might settle upon the regular masonry, finds its way through the intervals between the dry stones, and is thus conveyed down into drains, constructed beneath the floor of the gallery.

CHAP. XIX.

OF SUBTERRANEOUS FORTIFICATION, INCLUDING THE USUAL DISPOSITION OF COUNTERMINES, WITH THE NATURE AND EFFECT OF MILITARY MINES IN GENERAL.

A military mine is a subterraneous gallery or excavation, by means of which you may advance near to, and immediately under, your enemy's works or lodgements, in order to blow them up with gunpowder.

The art of planning and executing mines of the above description, is called SUBTERRANEOUS FORTIFICATION.

MILITARY MINES may either be offensive or defensive.

When the term "MINES" is used without further explanation, it always implies OFFENSIVE MINES, or those which are formed by a besieging army in the course of a siege.

Defensive mines being generally prepared before hand, in a permanent manner, in order to counteract the operations of any army,

that might at some future period attack a fortress, are called COUNTERMINES.

The galleries of countermines are usually reveted with brick-work or masonry, and arched over, so that their profiles differ in no respect from those of the galleries of communication, &c. which were before described. It will, however, be understood, that this remark does not apply to countermines, excavated in rock, which of course require no interior revetment.

The galleries of military mines have different appellations according to their size. There may be, for instance, a great gallery, a gallery, and a low gallery.

A GALLERY implies one, in which a middlesized man may walk without stooping, and in which two persons may pass each other without inconvenience.

A GREAT GALLERY implies one, which is higher than the former, and sufficiently broad for three or four men to walk abreast.

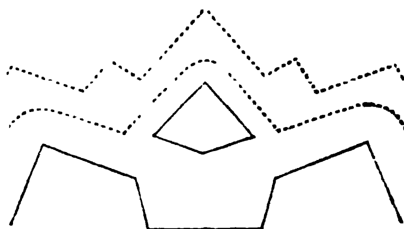
A LOW GALLERY is generally not less than 3 feet broad, but it is only 4 feet 6 inches high, or thereabouts, so that a man cannot walk upright in it.

Before we proceed further, it is to be observed, that various engineers have proposed various systems of countermines, differing very widely from each other, even in cases where the upper works of the fortress have been of the same construction. But to describe these systems in detail, or to enter into a discussion of the comparative merit of any of them, would not suit the plan of my present work. I shall therefore make such remarks only, as will serve to explain the nature of countermines in general, in a sufficient degree to qualify the reader, for afterwards perusing professed treatises on military mining to advantage.

The most useful galleries of a countermined fortress are those which extend under the covered way and glacis, as they serve to

retard an enemy's progress, by keeping him at a distance from the principal works of the place. The most common modes of disposing such galleries shall now be described.

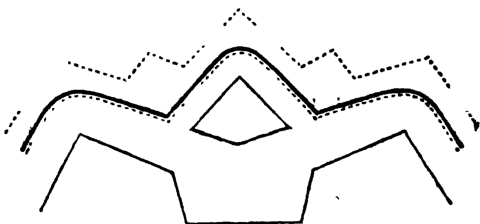
Draw the outline of a simple front of fortification, dotting the counterscarp and the crest of the glacis, and omitting the remainder of the latter work, for the sake of clearness.



THE PRINCIPAL OR MAIN GALLERY of the countermines, in almost every system of subterraneous fortification, is constructed close to the revetment of the counterscarp, and often goes all round, following the outline of that work; in which case, the salient parts are usually made wider than the rest of it, and are crenneled for the purpose explained in the preceding chapter.

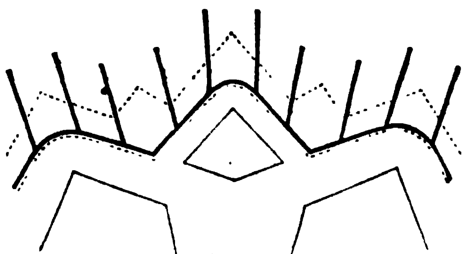
When a plan is drawn on a small scale, the galleries of countermines are either represented by spaces shaded dark, or by thick lines.

Parallel to the dotted counterscarp of your figure, and near it, you will therefore draw a thick line, to represent the counterscarp gallery of your countermines.



From THE COUNTERSCARP GALLERY, it is usual to push out a number of other galleries, towards the country, which are called DIRECT GALLERIES.

These direct galleries may either be parallel to the capitals of the places of arms of the covered way or nearly so, or if you think proper, they may be made nearly perpendicular to the long branches of the covered way.



In our present figure, there are five places of arms of the covered way. Parallel to each capital of the above places of arms, draw two direct galleries, one to the right, the other to the left of it, placing the whole as nearly at regular distances from each other, as is practicable.

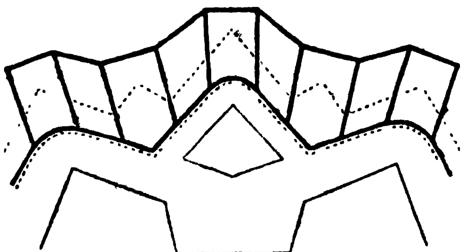
If a place were fortified with countermines according to the system, now represented, each front would, as you may perceive, have a counterscarp gallery and eight direct galleries.

In your present figure, no direct galleries are shown immediately under the capitals of your places of arms. It is to be remarked, however, that this is sometimes done, the disposition of countermines being susceptible of very great variety, as was before mentioned.

A more advanced gallery, constructed parallel to the counterscarp gallery or nearly so, is called an ENVELOPE GALLERY.

Those parts of the envelope gallery, which intersect the produced capitals of the places of arms, are usually made perpendicular to the said capitals, for a certain distance to the right and left of their common intersection. The remaining parts of the envelope may be nearly parallel to the branches of the covered way.

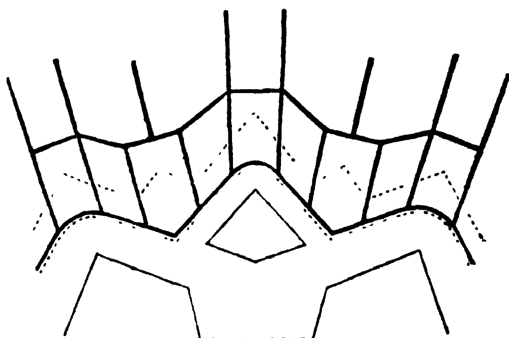
Draw an envelope gallery accordingly.



When an envelope gallery is used, the direct galleries seldom or never terminate there, as represented in our present figure, but

are commonly pushed forward to a considerable distance beyond it; which may either be done in the same allinement, or from new points, if you think proper.

Add to your figure, by drawing eight direct galleries in front of your envelope, six of which must be formed by producing six of your former direct galleries; but let the remaining two start from new points.



Those portions of the direct galleries, which connect the counterscarp gallery and envelope together, are sometimes, from that circumstance, called COMMUNICATION GALLERIES.

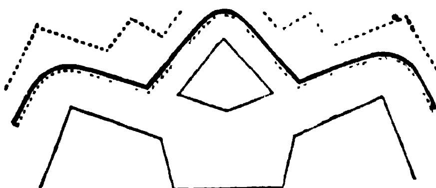
Those portions of the direct galleries, which are the most advanced under the glacis towards the country, are usually called LISTENING GALLERIES, because the miners of the fortress besieged keep watch there upon the enemy's operations.

Consequently, in our present figure, there is a counterscarp gallery, an envelope gallery, and direct galleries; the latter consisting, partly of communication, and partly of listening, galleries.

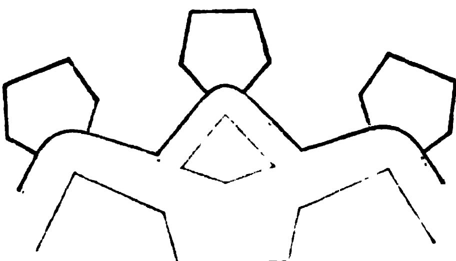
Some writers have recommended that there should be more than one envelope gallery; but it is unnecessary to draw a new figure to exemplify this construction, as the thing may easily be understood. When there are two galleries of this description, that which is the most advanced is called THE SECOND ENVELOPE.

A TRANSVERSE GALLERY is one, which is supposed to intersect the direct galleries nearly at right angles. This term, however, is seldom or never applied to any gallery of considerable extent, such as the envelope, but denotes a short gallery, perpendicular, or nearly so, to the produced capital of a place of arms

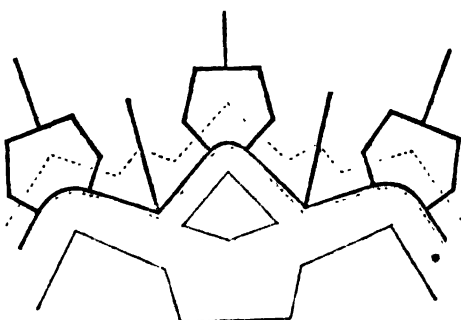
Rub out all your galleries, except the counterscarp gallery.



Draw a transverse gallery, in front of each of your three salient places of arms; and connect the flanks or extremities of these to your counterscarp gallery, by direct galleries. It is not, however, necessary, that direct galleries, constructed for this purpose, should extend in the same continued right line: they may either curve a little, or form an angle. You will therefore draw the new direct galleries, in your present figure, accordingly.

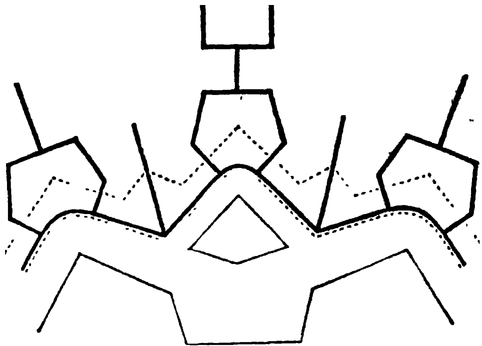


From the center of each of your three transverse galleries, draw a listening gallery; and from the reentering angles of the counterscarp, push out direct galleries, in the allinements of the capitals of the two reentering places of arms.



It was before observed, that there may be two envelope galleries, and in like manner, there may be more than one transverse gallery, in front of the same work.

Draw a second or more advanced transverse gallery in front of your ravelin, and from the extremities of it, push forward two new listening galleries.



Instead of direct, and transverse or envelope galleries, intersecting each other perpendicularly, or nearly so, galleries may be pushed out from the counterscarp, so as to intersect each other obliquely, in the form of the letters X or Y.

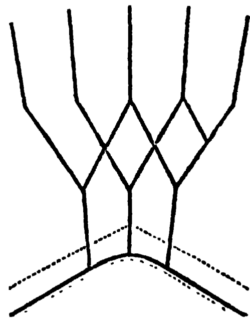
Rub out your figure.

Draw dotted lines to represent part of the covered way, in front of the salient angle of a bastion, ravelin, or other work. And draw also a thick line for a counterscarp gallery.



From your counterscarp gallery, draw three direct galleries, one under the capital, the others at equal distances to the right and left.

Having continued these direct galleries to a certain distance, in the usual manner, you will then, from the extremity of each, draw two galleries branching off obliquely both to the right and left, until the lines thus drawn form two intersections: after which you will draw direct galleries towards the country, from the advanced points of intersection, thus found.*



* With a view to give some precise notion of different dispositions of countermines, which have been actually proposed by engineers, who have

The part, where two or more galleries intersect each other, is called A JUNCTION. These parts should be made rather more spacious than the remainder of the galleries.

From the various figures, which you have now drawn to illustrate the usual disposition of defensive mines, you will have observed, that the galleries of countermines are laid out in such a manner as to intersect the glacis, nearly at equal intervals from each other, so that the ground is, by these various intersections, divided into spaces or COMPARTMENTS, in as regular a manner as possible. Consequently, on whatever part of the glacis an enemy may form a lodgement, the miners of the place besieged may always advance very near to the spot, by means of their various galleries, which, whilst they remain perfect, serve as so many subterraneous roads, whereby men may take post in any required position.

In order to make the most of this advantage, the besieged always endeavour to preserve the principal galleries of their countermines as long as possible; and for this reason, they do not lodge the gunpowder, intended for an explosion, in or near to these galleries, but in shorter ones, pushed out to a certain distance from them.

For instance, from the direct galleries, which advance under the glacis, shorter galleries are formed to the right and left, and from the transverse or envelope galleries, as also from the counterscarp gallery, short galleries are in like manner pushed out to the front.

The short galleries of the countermines, now alluded to, which are intended for the purposes of actual explosion, are called branches.

written on the subject, the present figure represents Marescot's system; the last finished figure (*See the first figure of page* 391) represents Mouzé's system; and the former figures (*See pages* 388 *and* 389) represent systems, which have been, frequently, either executed or recommended.

The BRANCHES are usually much smaller than the galleries of the countermines, which, as was before observed, serve principally for communications, and they are from their dimensions distinguished into two kinds, great and small.

A SMALL BRANCH is barely of such a size, as to allow men to work in it; and they cannot move, but on their knees, or by crawling on their hands and feet.

A GREAT BRANCH is of a medium size between the small branch and the low gallery.

The powder, in military mines, is not lodged exactly at the extremity of the gallery or branch, where the explosion is to take place, but in a recess, cut some feet to the right or left of it. This recess is called THE CHAMBER of a mine, and is usually represented in a plan by a small square or rectangle.

Draw two lines, parallel to each other, to represent part of a gallery of the countermines, as for instance an envelope or transverse gallery, on a larger scale than that of your former figures.

From any convenient part of it, draw a branch or narrower gallery perpendicular to it, at the extremity of which, and to the right of it, draw a small square to represent a chamber; and rub out superfluous lines.

In mining, whenever the direction of a gallery or branch is changed to the right or left, the angle thus formed is called A RETURN, as is the case, for example, in the chamber represented in our present figure.

Sometimes the same branch, after a certain distance, may lead to two, three, or more branches, diverging from it in various directions, each of which may have a chamber at the end of it.

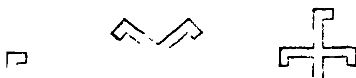
Draw a second branch, proceeding from the same gallery, parallel to the former, and of the same length nearly.

From the extremity of this second branch, draw two shorter ones, diverging to the right and left, with a chamber at the extremity of each.



Draw a third direct branch, extending from the gallery, parallel to the two former principal branches, represented in your figure, and of the same length nearly.

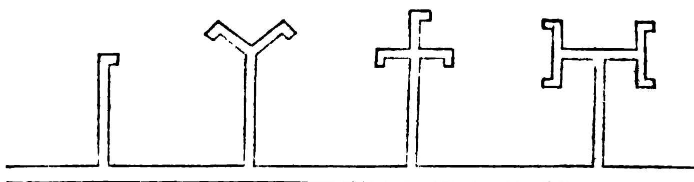
From the extremity of this third branch, draw three shorter branches, diverging from it, one in the same allinement, the others to the right and left. Draw also a chamber at the extremity of each.



Draw a fourth direct branch, extending from the gallery, parallel to your three former principal branches, and of the same length nearly.

From the extremities of this last branch, draw two shorter branches to the right and left, in a perpendicular direction, and let each of these also diverge into two new short branches at right angles to it.

And at the extremity of each of the four last-mentioned branches, draw a chamber.



Your figure now represents part of a gallery of the counter-mines, from whence proceed four principal branches, leading to ten chambers.

It is here proper to observe, that although the term "mine" is general, and may apply to the whole of any excavation, however extensive, it is in military language often used in a more limited sense, so as to denote that portion only, which is actually prepared for the purpose of explosion.

For example, our present figure may be said to represent a gallery, with branches, in the latter of which several mines are supposed to be established.

The mine, formed at the extremity of your first branch, is called A SINGLE MINE, having only one chamber, and consequently being only capable of producing one explosion.

The two mines, formed near the extremity of your second branch, constitute what is called A DOUBLE MINE, as they proceed from the same junction, and may be fired together.

For the same reason, the three mines near the extremity of the third branch constitute A TRIPLE MINE; and the four mines near the extremity of the fourth branch constitute A QUADRUPLE MINE.

Double, triple, quadruple, &c. mines, being intended to produce simultaneous explosions, are called CONJUNCT MINES, in order to distinguish them from single or INDEPENDENT MINES.

It is to be observed that the term "SPRINGING" is often used to denote the act of exploding a mine; so that A MINE, when exploded, MAY ALSO BE SAID TO BE SPRUNG.

In the defence of countermines, after all the branches leading from any part of an advanced gallery are used, the mines at the extremities of them, having been fired in order to annoy the besiegers, so that the ground there is consequently no longer favourable for the formation of new branches; it is then usual for the besieged to destroy that part of their gallery, for the purpose of preventing the enemy from penetrating by means of it;* whilst they themselves retire to their remaining galleries, of which they make successively a similar use.

In short, in subterraneous warfare, the same rule is followed, as in defending the upper works of a fortress. The most advanced parts are resolutely maintained, and the ground disputed inch by inch, in order to retard the enemy's progress, and keep him at a distance from the body of the place, as long as possible.

In addition to the countermines already described, which are formed under the covered way and glacis, galleries are also prepared for the protection of the outworks and main inclosure, after the enemy shall have made himself master of the counterscarp.

The galleries of a ravelin, bastion, &c. have different names according to their position. For example there may be a covering gallery, a scarp gallery, a rampart gallery, and a retired gallery.

A COVERING GALLERY denotes a gallery, constructed in front of, and parallel to, a scarp revetment. It protects a work, by impeding the enemy in his passage of the ditch, under which it is excavated.

A SCARP GALLERY denotes one, which is constructed close to the back of the scarp revetment of a work.

A RAMPART GALLERY denotes one, which is constructed at

* With this view strong doors are sometimes placed in various parts of the galleries, behind which the besieged miners retire, and either fire upon the assailants, or throw suffocating balls to annoy them, through crennels made for the purpose. In some galleries, deep trapholes, covered with tilting doors, have also been formed to impede an enemy's progress. This was done in the countermines of St. Philip's Castle in Minorca.

some distance behind the scarp revetment, either under the middle of the terreplein, or towards the rear of it.

A RETIRED GALLERY denotes one, which is constructed entirely in rear of the rampart of a bastion, ravelin, or other work, but which is supposed to be laid out parallel to it, unless any thing to the contrary is specified.

A CAPITAL GALLERY denotes one, which is constructed immediately under the capital of a work.

And in like manner, A REVERSE GALLERY and A GORGE GALLERY denote those, which are constructed in the reverse, or under the gorge of a work.

The position of such galleries may be sufficiently understood, without adding any new figures for the purpose of illustrating them. In their dimensions and use, they are similar to the former galleries, which have already been explained; branches, with proper chambers, being pushed forward from them, for the purposes of explosion, in any required direction.

It ought, however, to be understood, that the above various galleries have never been combined in the defence of the same work. On the contrary, more than one principal gallery, parallel to the scarp line of a work, has very seldom been used. The several positions, that have been enumerated, are therefore to be considered, as a specimen of the great variety of ideas and systems, before alluded to, which have prevailed as to the proper disposition of military mines.*

The object of countermines, used for the protection of a bastion, ravelin, or other work, is, first to impede the enemy in his

* There has been the same variety of opinion, as to the proper position of the principal gallery of the covered way. Some authors, for example, instead of placing it close to the counterscarp, have recommended that it should be formed more in advance, either under the middle of the terreplein of the covered way, or under the crest of the glacis.

passage of the ditch: secondly, to clear away the rubbish from the breach, so as to render it less practicable: thirdly, to blow up the hostile troops employed in an assault: and lastly, to destroy their lodgements, if they should eventually succeed in gaining possession of a part of the rampart.

It may perhaps be almost superfluous to observe, that the retrenchments of bastions, ravelins, and other works, may also be strengthened by means of galleries, in a manner exactly similar to that which has just been described.

Having explained the general nature and distribution of countermines, I shall next proceed to describe the mode of preparing an explosion, and the usual effect thereby produced.

When the soil is dry, the total quantity of gunpowder, intended for the charge of a mine, may be carried to the chamber in separate bags, each containing 40 or 50 pounds, which may be built up in a cubical form.

When the soil is damp, the outside of these bags may be greased, or, what is more common, a wooden COFFER OR POWDER BOX may be used, which is conveyed empty into the chamber, and is there filled with gunpowder.

Metal POWDER CASES of tin or copper may also be used for the same purpose, by way of greater precaution.

When a mine is loaded, that is to say when the charge of powder is deposited in the chamber, a considerable portion of the branch, which leads to the chamber, must be blocked up either with sand bags or rammed earth; or with a mixture of earth, stones, short beams of wood, &c. closely packed together.

After it has been blocked up in this manner, a mine is said to be tamped, and the earth and other materials, used in so doing, are called THE TAMPING.

The tamping is intended to create a great resistance to the explosion, in the direction of the branch or gallery, and the

chamber of a mine is formed with a return, as was before explained, for a similar reason, namely, in order that the gunpowder may act with the greatest possible effect, against the enemy's works or lodgements, which it is proposed to blow up. If these precautions were not taken, that is to say if the powder were lodged, not in a regular chamber, but at the extremity of the branch itself, and if it were then fired without previously tamping the mine, a considerable part of its force, when exploded, would be uselessly wasted in destroying the branch and the adjoining gallery.

As soon as a mine is loaded, a train of gunpowder, or other inflammable matter, is laid in a narrow channel or tube, extending backwards from the charge towards the rear of the branch, which must be properly covered and secured against accidents, before the operation of tamping is commenced.

THE TRAIN OF A MINE is usually contained in A POWDER HOSE, protected by casing tubes.

The hose may be made of strong linen, and should not be less than one inch in diameter.

The CASING TUBES are usually made of wood. The best mode of forming them is to take some narrow pieces of 1½ inch plank, and groove them longitudinally on one side. Any two of these, when applied together with the grooves inwards, will form a compact hollow tube, which must of course be rather larger in diameter, than the filled powder hose, which it is intended to contain.

The train of a mine is also sometimes called THE PRIMING, and after the train is laid, a mine is said to be primed.

After A MINE IS LOADED, PRIMED, AND TAMPED, it is fired by means of a piece of portfire, attached to the tail of the powder hose, or priming, and cut to such a length as to burn for one or more minutes, before it communicates with the powder, in order to give time for the miner who fires it, to retire to a sufficient distance.

Sometimes, by way of greater security against damp, the train

of a mine may be laid in metal PRIMING TUBES, made of tin or lead. These, if the former metal is used, may be inclosed in wooden casings, of the nature before described, to prevent them from being crushed by the tamping.

It will readily be understood, that the train of a mine serves merely as a communication through the tamping, upon the extent of which its length must depend. If no tamping were used, a long train would therefore be entirely unnecessary.

In conjunct mines, which are intended to produce two or more SIMULTANEOUS EXPLOSIONS, the train of each charge is led back to the junction, where it communicates with all the others, so that the whole of them meet in one point, and are fired at the same moment.

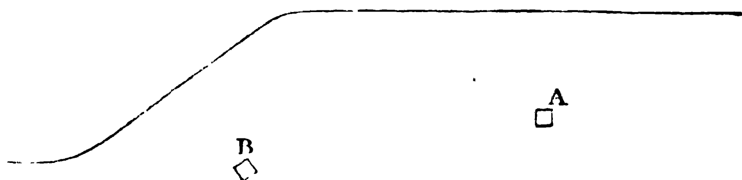
The various trains of a conjunct mine should all be exactly of the same length. The point, in which they unite, is called THE FOCUS OF IGNITION; whilst the center of the charge, contained in each chamber, is called THE FOCUS OF EXPLOSION.

When the term "focus" is used, in speaking of a single mine, without any further explanation, the focus of explosion is always implied.

When gunpowder is lodged under ground, and exploded, it has a natural tendency to act with equal force in all directions: but as it is opposed in acting downwards and laterally, by a much greater resistance than it is able to overcome, the principal visible effects of the explosion are always produced, in the direction of the nearest surface, where it meets the least resistance.

To exemplify this by a figure, draw an outline to represent the surface of the ground, partly horizontal, and partly sloping at an angle of about 45 degrees: which being done, below the horizontal surface, draw a small square, A, to represent the chamber of a loaded mine, and near the sloping surface, and at an equal dis-

tance from it, draw a second small square, B, to represent the loaded chamber of a second mine.



From the focus of the mine, A, draw a line, A a, perpendicular to the nearest surface, which will be a vertical line, and from the focus of the mine, B, draw, in like manner, a line, B b, perpendicular to the nearest surface, which will of course be oblique to the horizon.



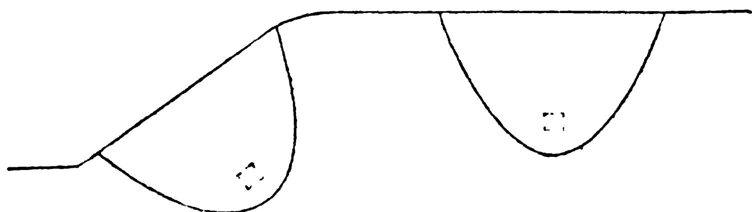
These being the shortest lines, that can be drawn from each focus, to the nearest surface, there will consequently be a smaller mass of earth to resist the action of the powder, in the direction of these lines, than in any other direction. For this reason, the line, A a, is called the line of least resistance of the mine, A; and the line, B b, is called the line of least resistance of the mine, B.

When a mine is exploded, under ground, under the circumstances represented in our figure, it blows up or shatters the surrounding earth in such a manner, as to form a cavity shaped not unlike a bowl or bason. This is called THE CRATER of the mine.

In earth of uniform tenacity, the crater of a mine is often nearly regular in its appearance, which however is not alike in any two similar cases; and therefore the investigation of its precise form, which many writers have attempted to fix by mathematical calculation, is a pursuit absolutely chimerical. But as an ap-

proximation to the truth, with a view of merely finding the average quantity of earth, affected by the action of gunpowder; an inverted parabola, of which the axis agrees with the direction of the line of least resistance, and of which the vertex is deeper under ground than the bottom of the chamber, may generally be assumed, as a tolerably accurate section of the crater of an exploded mine. The mean diameter of the crater at the surface, for although nearly, it is not always exactly, circular, as well as the depth, to which it extends below the focus, will be greater or less, in proportion to the quantity of powder used in the explosion.

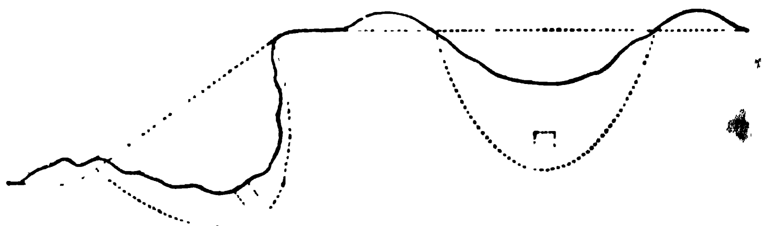
Upon each of the lines, A a, and B b, as an axis, produced about one third of its original length, you will therefore draw a parabola, to represent the sections of the craters, supposed to be formed by the mines, A and B, when exploded; making the width of each crater at top equal to twice the line of least resistance: and let the original chambers, A and B, be dotted.



But although, on examination, the whole of the earth, contained within the outline of each crater, will be found to have been affected by the explosion; it is to be remarked, that those particles of it, which are below the focus, are not always actually thrown out, but sometimes merely bruised and impelled downwards, with a compressing force: and in any mine, such as that marked A, in our last figure, whose greatest force is exerted vertically, a considerable portion of the earth, which is either actually blown out of the crater, or moved to a certain height above its original position, falls down again, into the same place nearly, after an explosion. In a mine, such as B, on the contrary, which acts in an oblique direction, a much

smaller portion of the exploded earth finds its way back into the crater, as it is chiefly impelled laterally.

Consequently the section of each crater, as it appears after the explosion, does not assume a form nearly coinciding with those represented in our present figure, in average dimensions, until all the loose earth has been removed. The actual state, in which the explosion leaves them, will be shown more correctly by the following figure, in which the space contained in each crater, between the dotted curve and the other, shows such parts of the original earth as are injured, but not finally removed from the spot, by the action of the gunpowder.

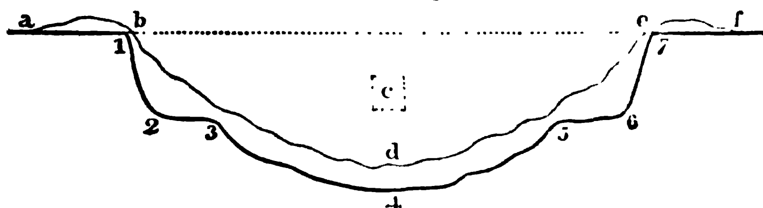


It is to be observed, that the parabola is, in almost all cases, a tolerably correct representation of the section of a crater, in the state in which it is actually left by the explosion. But after the whole of the loose earth, which is either moved or injured by the effect of a mine, is cleared out; then the section of the crater will often be found to differ very widely from the above figure, which, as I before observed, was merely chosen by way of approximation. Sometimes, for example, an emptied crater has the form of an inverted frustum of a cone nearly.* Sometimes the upper part of it only has that form, whilst the lower part of it resembles a shallow dish or saucer, so that in section this part

* When an upright cone is cut through horizontally, the upper part of it towards the vertex forms a smaller but perfect cone, similar to the original body. The lower or imperfect portion, into which it is thus divided, is called the frustum of a cone.

may be represented by a very obtuse parabola: and there is often a kind of irregular berm, extending all round the interior of it, at a certain depth.

To explain this last-mentioned form, which is very common in practice, an additional figure is given, in which the right line, a f, represents the original surface of the ground: whilst the dotted square, c, shows the position of the powder box.



The curve, a b d e f, the concave part of which is nearly parabolical, shows the actual form of the crater immediately after the explosion; whilst the irregular figure, 1 2 3 4 5 6 7, shows the form, above alluded to, which it will be found to have, when all the loose stuff is cleared out. In this, the upper part, bounded by the lines, 1 2, and 7 6, resembles the frustum of a cone nearly: below which is the irregular berm, represented in section by the lines, 2 3, and 5 6; whilst the bottom part, 3 4 5, immediately under the original position of the charge, is parabolical.

The principal difference, to be remarked between this and our former figure, is that, in the present instance, the earth is supposed to be expelled to a very considerable depth below the original chamber; an effect, which always takes place when extraordinarily large charges of gunpowder are used. The superior diameter of the crater is also much greater, in proportion to the line of least resistance. More moderate charges, on the contrary, produce the less violent effects, represented in our former figure.

When there is no line of least resistance, properly so speaking, as for example, supposing a quantity of gunpowder to be lodged in the center of a globular mass, equally strong on all sides, then no

crater would be formed in the event of explosion; but the whole mass would be blown into fragments in all directions, as is shown by the bursting of a bomb shell.

There is another case, even in subterraneous explosions, where no regular external crater would be formed, that is, when the quantity of powder, lodged in the chamber of a mine, is too small to overcome the resistance of the earth above it, so that no visible effect is produced at the surface, which at the utmost will merely be cracked by such an inadequate charge. On digging down to the spot, where the powder was placed, an internal crater, of an irregular globular form, will, however, sometimes be found; a part of which, at least in stiff soil, will often be quite hollow, the remainder of it being filled with earth loosened by the explosion. This is called A SMOTHERED MINE.

The line of least resistance is often, for the sake of conciseness, simply termed THE LINE OF A MINE. This line is of the greatest importance in military mining; for upon its length depends the quantity of powder, which it is proper to use, in order to produce a required effect, in soil of a given tenacity; and it also serves as a scale for measuring the comparative power of different mines.

For example, a quantity of gunpowder which is just capable of producing a crater, whose diameter shall be double the line of least resistance, is called AN ORDINARY CHARGE, and a crater of this proportion is called AN ORDINARY CRATER, OR A TWO LINED CRATER. A crater, which is three times the line of least resistance in diameter, is called a THREE LINED CRATER. A crater, which is four lines in diameter, is called A FOUR LINED CRATER: and in like manner, there may be A FIVE LINED CRATER, a SIX LINED CRATER, &c. &c.

When a mine is loaded with a quantity of powder, which is too small to produce a two lined crater, it is termed AN UNDERCHARGED MINE; but if it were loaded with a quantity of powder, capable of producing a much greater effect than the above, it would be termed A SURCHARGED MINE; and the charges of such mines

are called EXTRAORDINARY CHARGES. These are distinguished from each other, in proportion to their intended effect, by the same terms, before applied, in speaking of the craters of mines.

Thus for example, there may be an ordinary charge, a three lined charge, a four lined charge, a five lined charge, a six lined charge, &c. &c.

And in like manner, a mine, intended to produce a given effect, may be termed an ordinary mine, a three lined mine, a four lined mine, a five lined mine, a six lined mine, &c. &c.

A mine is also distinguished by the depth or length of its line of least resistance, expressed in feet. Thus for example, A TEN FOOT MINE denotes one, which has a line of 10 feet: A FIFTEEN FOOT MINE denotes one, which has a line of 15 feet, and so on.

Surcharged mines, particularly when loaded with extraordinarily large quantities of powder, have often been styled GLOBES OF COMPRESSION. This term is by far too vague to convey any distinct notion of the proposed effect of an explosion, but having been very generally used, it would not be proper to omit it.*

When the line of a mine is given, the proper ordinary charge, or one capable of producing a two lined crater, in soil of a middling tenacity, may be found with sufficient accuracy by the following simple rule

RULE. Cube the line of least resistance in feet, and one tenth of the result (fractions being disregarded) will be the required quantity of powder in pounds.

Thus for example, supposing the line of least resistance of a mine to be 12 feet: the cube of 12 is 1728, which being divided by 10, and the fraction struck out, gives 172 lbs. of powder, as

* The pompous term "globe of compression," which signifies nothing more than a common military mine, loaded with an unusually great quantity of powder, was first introduced by Belidor, for the purpose of illustrating his theory of the action of gunpowder in mines; but however applicable to theoretical purposes, such high-flown expressions should, as much as possible, be banished from practical language.

the proper charge for producing an ordinary crater, in common soil. In soil of a different nature, more or less powder might, of course, be required to effect the same purpose.

It is not my intention to treat at large of the rules for finding the proper charges of mines under various circumstances; suffice it to say, that in mines of different depths, when similar craters are to be produced, the proper charges will be nearly in proportion to the cubes of their respective lines, as may be inferred from the foregoing rule. But in mines of the same depth, when more than two lined craters are proposed, the powder proper for extraordinarily large charges must be increased, in proportion as a greater effect is intended, in a considerably greater ratio, than that whereby the square of the diameter of the proposed crater exceeds the square of the diameter of an ordinary crater.*

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* From experiments recently made at Chatham, in soil of uniform tenacity, consisting of fine sand mixed with clay, weighing about 124 lbs. per cubic foot, and capable of standing without support in the form of a small gallery, the undermentioned conclusions as to the proper charges of mines in such soil have been drawn.

RULE. Multiply the cube of the line of least resistance, in feet, by the following numbers, which will give the charges, in pounds, necessary for producing the following effects: viz.

In order to produce a one lined crater, multiply by ·033 (*or in other words divide by* 30): To produce a two lined crater, multiply by ·095: For a three lined crater, multiply by ·21: For a four lined crater, multiply by ·45: For a five lined crater, multiply by ·93: For a six lined crater, multiply by 1·75: For a seven lined crater, multiply by 2·25: For an eight lined crater, multiply by 3: For an 8½ lined crater, multiply by 6·5: And for a nine lined crater, multiply by 12.

In a one lined crater, the earth is either merely agitated, or only raised a very little higher than the surface, and then falls down again into its original position nearly. In a four lined crater, it is blown out to a depth equal to the line of least resistance, and is affected to 1½ times that depth. And in a nine lined crater, it is blown out to the depth of 2½ times the line of least resistance, and is affected to 2¾ times that depth. But it is to be remarked, that there is little certainty in these proportions, for the mean depths of two craters, under similar circumstances, usually differ more than their mean diameters.

It was before stated, that the action of gunpowder, in all but smothered mines, forms a crater of a certain diameter, which extends

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In the course of experiments, above alluded to, we found that Belidor was mistaken in his supposition, that it was impracticable to produce more than a six lined crater, by the greatest possible quantity of powder that can be used; and still more so, in the assertion, that in all cases about 300 times the line of least resistance, in feet, is the proper charge, in pounds, necessary for the above purpose. For we, by a charge of only 10 times the line of least resistance, obtained a six lined crater; and by a charge of 108 times the said line, we obtained a nine lined crater. which, according to his doctrine, ought to have been impracticable. But it is to be observed, that all our charges were placed at a small distance from the surface. Had our chambers been sunk five or six times deeper than they actually were, then instead of producing a six lined crater, by a much smaller proportion of powder than Belidor prescribes, it would have required a considerably greater charge than his, to obtain the said effect. For the powers necessary to move similar solid bodies are in the proportion of the cubes of their like sides, not in the proportion of the said sides themselves, as is implied in Belidor's proposition.

Notwithstanding these very palpable objections to that author's erroneous rule of multiplying the line of least resistance always by 300, in order to find the proper charge of what he calls a globe of compression, it has been implicitly copied by all the subsequent French writers on the same subject, up to the present day: and it is to be observed that all their recent books on military mining abound with practical errors of a similar nature. Witness the peculiar mode of sinking a shaft, proposed by a Captain Boule, which they universally hold out, as being in many cases the best and most expeditious method of performing that operation; but which, it may be presumed, none of them have ever tried, for it is not only very absurd, but generally speaking impracticable.

In these remarks, which I could easily corroborate by a number of similar examples, I do not mean to undervalue the labours of Belidor, who was the first that brought the art of military mining to any degree of perfection: but as far as regards his disciples, the more modern French writers on the same subject, who also have their merit, I take this opportunity of recommending, that their works should never be read without due caution and discrimination; since they have not in general taken the trouble, to draw a proper line between untried projects, and established facts; and instead of having recourse to experiments, they have been much too fond of indulging their imagination in the invention of new systems, and much too credulous in copying from their predecessors.

downwards, or laterally, only to a comparatively small distance from the focus, by reason of the greater resistance opposed to the explosion, in these directions, by the solid mass of earth. If, however, instead of being solid on all sides, there were any cavity in the earth, such as a gallery or branch, either below or on one side of the supposed mine, within a given distance from the focus, then the effect of the explosion would be different, for it would not only form an external crater, but would also act with considerable force towards the cavity, on account of its meeting with less than the usual resistance, in that direction. Consequently, a loaded mine will blow in and destroy any neighbouring gallery, at a much greater distance, than its sphere of action could possibly extend to, in solid earth.

It has been found by experiment, that a surcharged mine, capable of producing a six lined crater, will destroy subterraneous galleries, at the distance of more than four times its own line of least resistance from the focus. For which reason, such mines have been more commonly used by the assailants than by the defenders of a fortress; the latter, as was before observed, being desirous to protract the operations and preserve their own galleries, as long as possible.

In consideration of what has just been explained, it has been judged prudent, in using ordinary charges, not to establish the chamber of a mine nearer to any gallery, which you wish to preserve, than twice the line of least resistance. Indeed a greater distance may be considered desirable. For the same reason, the tamping of a loaded mine should extend at least 1½ times, or twice the length of the said line; and in single mines, which are to act successively, if their chambers are placed nearer to each other than the above distance, care must be taken before any of them is fired, to load and tamp the adjoining ones on each side.

The chambers of mines may, of course, be formed at very different depths or levels, according to the object proposed. Some

engineers have recommended establishing chambers within a short distance of each other, on three different levels or stages. By this means, after the first or upper tier is exploded, a new lodgement, formed nearly on the same spot, may be destroyed a second time by the middle tier, and a similar process may be repeated a third time by the lower stage or tier.

In MINES OF SEVERAL TIERS OR STAGES, the chambers are never formed vertically under each other, but obliquely at a certain distance, which even, when measured horizontally, as it would appear in a plan, is usually not much less than 1½ times the line of least resistance; and the difference of level between each stage, when there are more than two, seldom exceeds 5 feet.

The general level of the galleries of countermines may sometimes be considerably lower than the spot, where the entrance to them is formed.

In that case, it is usual to sink a square or circular pit, resembling a well hole, perpendicularly downwards to the requisite depth, through which men may descend into the gallery, by means of winding staircases, ladders, &c.

In mining, any pit excavated for the above purpose, is called A SHAFT.

The shafts of countermines are usually reveted with masonry: those of offensive mines are secured by woodwork.

It is to be remarked that shafts, like galleries, may serve, not only for the purposes of mining, but also as communications; and in the latter case, they should be more spacious than usual, and ought to have at least two winding staircases, carried up the circumference, at equal distances from each other in every corresponding part. Shafts of communication of this nature are however seldom necessary, except on fortified heights.

Sometimes, instead of using shafts, in mining, the necessary depths or levels may be gained, by making the galleries ascend

or descend, from one level to another, according to an inclined plane.

When the difference of level is considerable, in INCLINED GALLERIES, steps will be necessary; but when gradual, a slope without steps may be sufficiently convenient.

The nature of ASCENDING OR DESCENDING GALLERIES may be sufficiently understood without a figure. One section only shall be added, to show the manner in which the galleries of countermines may extend under a glacis.

Draw a counterscarp, covered way, and glacis, in section.

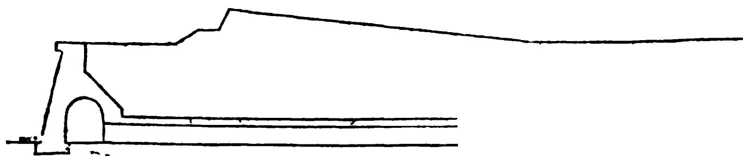
Draw also a counterscarp gallery, similar to that which you before drew, but you need not represent any loophole.



From your counterscarp gallery, draw a right line extending under the glacis, to represent the level of the floor of a direct gallery.

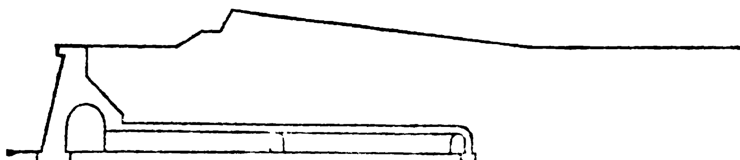
Draw a second line over the former and parallel to it, to represent the level of the roof of your direct gallery.

Rub out those lines of your counterscarp gallery, which will become superfluous as soon as the new gallery is drawn: and then draw a third line parallel to the former, to represent the top of the arch of your direct gallery.



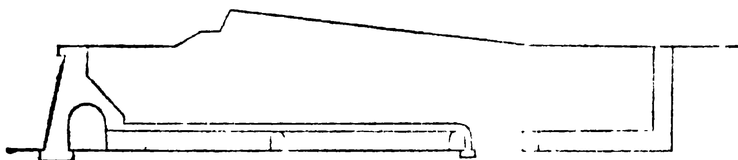
About the middle of your direct gallery, draw a figure to represent the entrance of an envelope gallery, seen in elevation, of the same height as your direct gallery.

At the extremity of your direct gallery, draw a similar figure, to represent a return or branch, leading to one of the most advanced chambers.



Beyond this, draw two vertical lines from the surface downwards, parallel to each other, to represent the sides of a shaft formed by the besiegers, in order to attack the countermines.

Draw also a portion of gallery or branch, pushed out from the above shaft, which will be represented by two parallel lines only, at the extremity of which draw a rectangle to represent a return leading to the chamber of an offensive mine.



The entrance of the shaft, &c. supposed in the above section to be excavated by the besiegers, would of course be protected by a parapet, thrown up in front of it towards the fortress. This work is omitted in our figure, in order to avoid confusion.

The galleries of countermines only are prepared beforehand, in a permanent manner; the various branches and chambers, which may be required for the purposes of explosion, being usually formed during the period of a siege, or at the time when a siege is confidently expected.* Such being the case, they cannot of course

* In a fortress founded upon rock, not only the galleries, but also the principal branches and chambers of the countermines, should be executed beforehand.

be reveted with masonry. Woodwork is therefore used to prevent the earth from falling in; and the same method is practised by the besiegers, in their offensive mines.

The woodwork of shafts and galleries is composed of frames and planks, the former of which are placed at intervals, not exceeding 4 feet apart, measured from center to center.

A SHAFT FRAME is usually made square, and consists of four pieces.

A GALLERY FRAME, or BRANCH FRAME, is made rectangular, and when put together and set up resembles a common door or window frame, in its appearance. Each of these last mentioned frames also consists of four pieces, namely ONE GROUNDSILL laid as a sleeper, two STANCHIONS, and ONE CAPSILL.

In a gallery or branch, there are ROOFING PLANKS to cover the top, extending from one frame to the other, AND SIDE PLANKS to line the sides of the excavation. The latter may often be dispensed with, but it is always prudent to use the former, even in stiff soil; excepting however sound chalk, and other substances, which local experience may have proved to be capable of standing without support.* The roofing planks and side planks are sometimes called, by miners, THE TOP SHEETING, AND SIDE SHEETING.

The sides of shafts must also be secured by planks, extending from frame to frame.

Miners, employed in digging a shaft, are said to be SINKING it, whilst the term "DRIVING" is applied to the formation of a gallery or branch; and the advanced extremity of any gallery or branch, where the men are at work, is called THE HEAD OF THE MINE.

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* A figure nearly resembling a gothic arch, that is to say, an arch composed of two segments of a circle, intersecting each other at the crown, is the best adapted for the section of an unsupported gallery.

In excavating the galleries of countermines, for the purpose of reveting them, frames and planks or sheeting must also be used, in the first instance, before the arches are built. These should not, however, resemble the rectangular frames, &c. of the temporary mines, before described, but should be made and put together, according to the system used, in tunnelling, in civil works; and the excavation should never be pushed on, more than 6 or 8 feet beyond the masonry.

After driving a gallery to a certain extent, which varies according to circumstances, but seldom exceeds 80 or 90 feet, at the utmost; the air will become bad, so that lights will no longer burn, and it will be impossible for the miners to continue their work, unless shafts or air-holes are pierced through the roof of the gallery, to produce a proper ventilation. But as external apertures of the above nature might be inconvenient and prejudicial, in subterraneous warfare, by affording an opportunity to the enemy of destroying or injuring the gallery, other means must generally be resorted to.

For this purpose A VENTILATOR must be placed, at or near the shaft, or entrance of the gallery, by means of which atmospheric air must be constantly impelled, through proper pipes, to the very extremity or head of the mine, as long as men are at work there. This precaution being taken, a gallery may be driven to any required extent, without the least difficulty; and after any explosion, the smoke, which makes it necessary for men to abandon the gallery, for a certain time, may be drawn off much more speedily, by the same process.

Various expedients may be used for throwing air into a mine, as for instance, any species of forcing pump, winnowing machine, &c. but in common cases, a pair of large forge bellows forms by far the simplest and best kind of ventilator that can be adopted. THE AIR PIPES should not on any account be pliant, and therefore metal pipes in joints are preferable to leathern hose, which

have also sometimes been used for the same purpose, and which, unless stiffened by hoops, placed internally at very small intervals apart, are constantly getting out of order.

Before we conclude the subject of mining, it is proper to observe, that a mine on a very small scale is usually styled A FOUGASS.

Fougasses are chiefly used in the defence of intrenchments or field works. Their line of least resistance is usually from 4 to 6 and not exceeding 8 feet. They are generally formed, not by subterraneous excavation, but by merely sinking trenches, for receiving the charge and train, which after these are laid, are immediately filled up again.*

In subterraneous warfare, a fougass also implies an undercharged mine, used by the besieged, which without producing any external crater, or considerable apparent effect at the surface, is intended solely for the purpose of interrupting the operations of the enemy's miners, by blowing in the sides of their galleries and branches, whilst in a state of progress. A fougass, applied to this particular purpose, is also called A STIFLER.

A kind of fougass may be formed, for the defence of rocky positions, by excavating in the rock itself, in any convenient situation, a cylindrical cavity, with a smaller chamber at the bottom, about 3 or 4 feet deep, and from 1 to 1½ foot in diameter, the axis of which should be inclined, at an angle of about 45° with the horizon, in the direction by which an enemy must advance. A charge of powder being placed at the bottom of this cavity, the remainder of it is filled with stones, which, on firing the powder

* The same mode must be adopted, in constructing permanent galleries, in soil consisting entirely of very fine loose sand, which it is impossible to do, by subterraneous excavation: and in other cases, even when the latter method is not absolutely impracticable, the former may sometimes be the most economical, and therefore the best.

by a train, in the usual manner, will be thrown out with great violence, in the direction of the axis of the cylinder, in the same manner, and with the same effect nearly, as if they had been fired from a common mortar. And for this reason, the contrivance, which has just been described, is called A ROCK MORTAR.*

It is to be observed, that a similar effect may take place, under certain circumstances, even in a common mine. If on one particular side of the chamber of a loaded mine, for example, there were a great quantity of stones, either purposely placed there by the miners, or naturally intermixed with the original soil, whilst on all other sides there was fine earth only; then, in the event of explosion, a shower of stones would be thrown out with great violence in one direction only, by the fall of which persons might be killed or wounded, whilst those who stood at an equal distance, in other directions, would be exposed to little or no injury.

When a great quantity of gunpowder is brought up close to an enemy, for the purposes of destruction, not by a subterraneous excavation, but by means of a vessel, in operating upon the water, or by means of waggons or other vehicles, in acting by land, the apparatus thus employed, is termed AN INFERNAL MACHINE.

When a quantity of powder is so secured, as to act either under water or very near the surface, in order to destroy a ship, floating

* Rock mortars have been formed in Gibraltar, Minorca, and Malta. In the latter island, we fired one, by way of experiment, with a charge of 90lbs. of gunpowder, which covered a great part of St. Julian's cove, at the head of which the mortar was excavated, by a shower of stones. The rock, being of a soft nature, was so much injured by the explosion, that two more rounds would probably have rendered it unserviceable. Rock mortars, generally speaking, are not to be recommended; but it is right that the nature of them should be understood, for in certain cases they might not be altogether useless.

bridge, boom, &c. the apparatus employed for this purpose, which is stowed away in a small compass, so as not to attract observation, and is sent forward by surprise, if possible, is styled A TORPEDO.

Having now sufficiently described the nature of subterraneous fortification, and of military mines in general, we shall return to the consideration of such upper works, as have not yet been explained.

CHAP. XX.

OF OUTWORKS, ADVANCED WORKS, AND DETACHED WORKS.

I have hitherto only described the tenail and ravelin, in addition to which, various other outworks, advanced works, and detached works, are used in fortification, some of which shall now be explained. It is proper, however, previously, for the sake of precision, to point out the distinction between the various kinds of works, which have just been enumerated.

The term, OUTWORK, implies any work, which is constructed within the limits of the general covered way and glacis of a fortress.

AN ADVANCED WORK implies a work, constructed beyond the covered way and glacis of a fortress, but either near to the foot of the glacis, or at a moderate distance from it, that is to say, not exceeding 250 yards, or thereabouts. Consequently such a work lies under the protection of the fire of the fortress, from which it may derive great support, in the event of an attack.

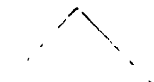
A DETACHED WORK signifies one, which is constructed at a considerable distance beyond the glacis, as for instance at the distance of about 800 yards, or more; so that, when attacked, it cannot derive any very effectual support from the fire of the fortress, but must depend chiefly on its own strength and resources.

Having made these necessary definitions, we shall proceed with our proposed subject.

A COVERPORT is a very small work, erected immediately before a gateway, in order to screen it, in any form judged the most convenient for that purpose.

A COUNTERGUARD is a more extensive outwork, usually consisting of two faces only, constructed in front of some other work, of greater importance, which it is intended to cover.

Draw two faces, forming a salient angle, to represent the faces of a counterguard.



Draw two other lines, at a small distance in rear, parallel and nearly equal to the former, to represent the reverse of your counterguard.



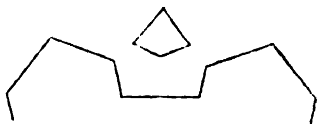
Draw the two extremities of your counterguard, by connecting the ends of the two sets of parallel lines, which compose your figure.



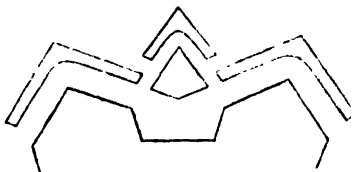
Your counterguard is now complete.

A counterguard may be placed, either in front of a bastion or of a ravelin.

Draw two bastions, connected by a curtain, in order to represent part of the main inclosure of a fortress. Draw also a ravelin, in the usual manner.

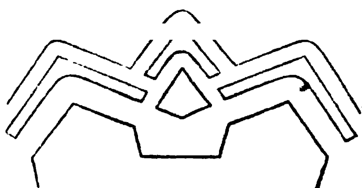


Draw three counterguards, similar to that which you have already drawn; two of which you will place before your two bastions, the third in front of your ravelin: and let the faces of these counterguards be parallel to those of the bastions and ravelin, or nearly so.



Beyond the counterguards are ditches, communicating with the main ditch, after which comes the covered way and glacis, as usual.

Complete the form of these ditches, by drawing the counterscarp lines of your present figure.



Counterguards are also sometimes called COVERFACES, from their situation and object; but the former term is the most common.

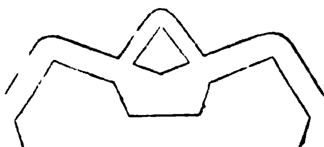
Counterguards are usually made very narrow, allowing barely space enough for guns in their terreplein. This is done in order that an enemy, after taking these works, may not have room for forming convenient lodgements and batteries, in the interior of them.

Counterguards are seldom placed before ravelins, except with a view of improving ancient fortresses whose ravelins are considered too small. When the ravelin is large, the addition of a counterguard in front of it is not considered advisable.

If the three counterguards, represented in our present figure, were altered by producing their adjoining extremities, until they met each other, without leaving any intermediate ditches; they would then constitute, what is called, a continued counterguard. This construction being exceedingly simple, it has not been judged necessary to give any figure, for the purpose of exemplifying it.

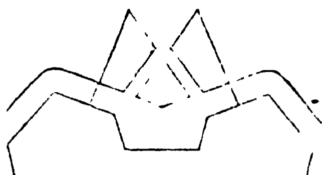
A CONTINUED COUNTERGUARD, when carried round to any considerable extent in front of a fortified inclosure, is also styled AN ENVELOPE, OR AN ADVANCED INCLOSURE, without any reference to its general form, which may either be parallel to the outline of the principal works immediately in rear of it, or not. The suburb called the Floriana, in Malta, is fortified with a double inclosure, in this manner.

Rub out your counterguards, and their counterscarp, leaving only the two bastions and ravelin; and draw a new counterscarp in front of them.

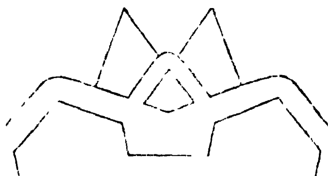


Sometimes an outwork, consisting of one long and one short face, is placed on each side of the ravelin of a front of fortification. Outworks of this kind are called TENAILLONS.

From the middle of each face of the demibastions of your front of fortification, draw perpendiculars towards the country; and produce the faces of your ravelin, outwards, until they meet the said perpendiculars.

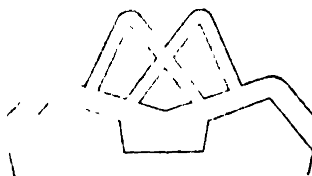


Rub out those parts of the above perpendiculars and produced faces, which cross the ditches of your figure.



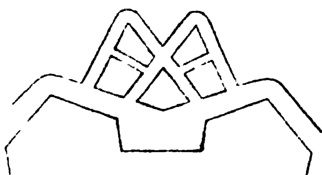
The remaining lines will represent the faces of your two tenaillons; one of which works covers the right face of the ravelin, whilst the other covers the left face of it.

Draw the ditches of your tenaillons, in the usual manner; making them equal in breadth to that of the ravelin; which being done, rub out those parts of the counterscarp of your present figure, that will become superfluous.



TENAILLONS usually have cuts formed across them to serve as retrenchments, in case the enemy should storm these works near the salient angle.

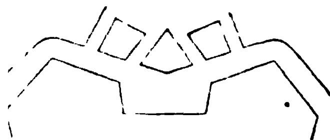
Draw a cut in each tenaillon, perpendicularly across it, or nearly so, terminating near the middle of the long face.



Draw also the ditches of these cuts.

Sometimes, instead of covering the whole of the two faces of a ravelin, tenaillons have been made smaller, so as to cover only about one half of them.

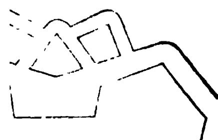
Rub out the advanced parts of your two tenaillons; leaving only that part, of each of them, which is in rear of the cuts.



Rub out also the corresponding parts of the counterscarp of your figure.

Small tenaillons now remain, which being only about half the size of your former ones, are called DEMITENAILLONS or half tenaillons.

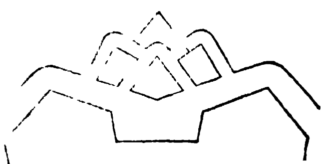
Complete the imperfect parts of the ditches of your demitenaillons, and ravelin, in the usual manner.



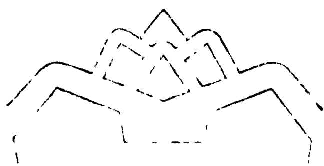
The demitenaillons are not considered good works in proportion to their expense, because they leave the ravelin too much exposed.

In order to remedy this defect, in places fortified with demitenaillons, it has been usual to add a small counterguard, in front of the salient angle of the ravelin.

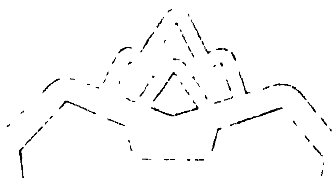
From the middle of each short face of your demitenaillons, draw right lines outwards or towards the country, parallel to the faces of your ravelin or nearly so.



Rub out those parts of the said parallels, which cross the ditches of the demitenaillons; and the remaining parts of them will represent the faces of your counterguard: the form of which is now complete, in every thing excepting its ditch.



Draw the ditch of your small counterguard in the usual manner; and rub out superfluous lines.



A small counterguard of this description, which does not cover the whole of the faces, but only the salient angle, of a ravelin or other work, is called A BONNET.

In your present figure, you may see clearly exemplified the manner in which various works may flank each other.

The bonnet, which is the most advanced work, is flanked by the short faces of the two demitenaillons:

The short faces of the demitenaillons are flanked by the ravelin:

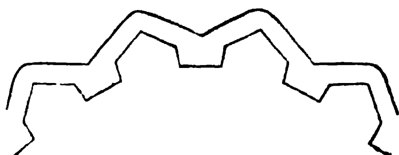
And the ravelin itself is flanked by the bastion, as was before explained.

The system of outworks, represented in your present figure, has been formerly used in some fortresses in the Netherlands; but is not at present considered good.

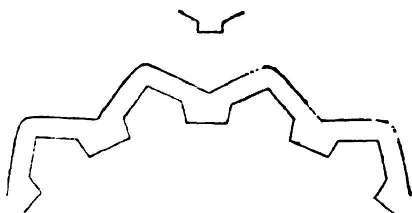
The largest kind of outworks, in use, are called hornworks, and crownworks, which shall next be described.

A HORNWORK consists of one front of fortification and two wings.

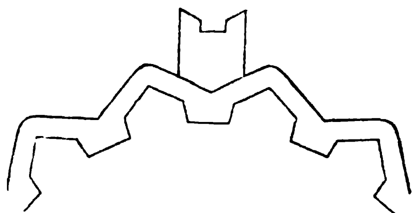
Draw four bastions, joined by curtains, to represent part of the main inclosure of a fortress. Draw also the counterscarps of the same.



Before the center curtain of your figure, at some distance from it, draw a detached front of fortification, to represent part of the proposed hornwork.



From the two extremities of this detached front, draw two right lines, extending as far as the counterscarp.

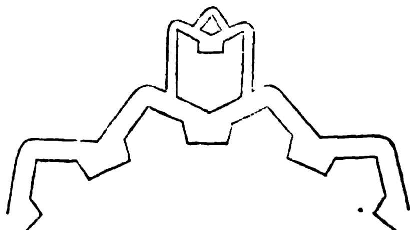


The last drawn lines form THE WINGS OF THE HORNWORK, the outline of which is now complete.

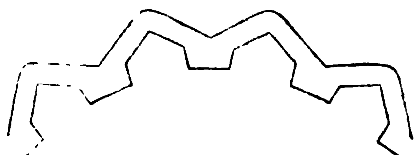
A hornwork may have a ravelin in front of it. It has also its ditches, communicating with those of the body of the place; beyond which it may have its covered way and glacis.

These details may easily be understood. We shall therefore only add a ravelin and ditches to our present hornwork.

You will make the above additions to your figure, accordingly; and rub out that part of the original counterscarp, which will become superfluous, after the ditches of the hornwork are drawn.



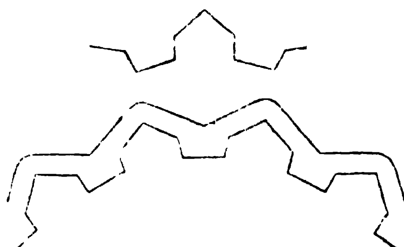
Rub out your hornwork, and restore the body of the place to its original state.



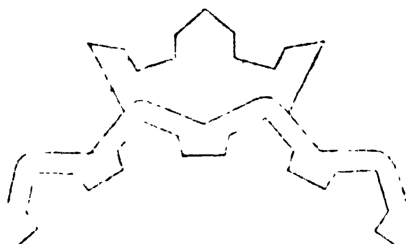
This being done, we shall next proceed to draw a crownwork.

A CROWNWORK consists of two fronts of fortification and two wings.

Before the center curtain of your present figure, at some distance from it, draw two fronts of fortification.

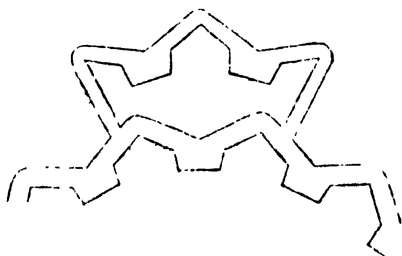


From the extremities of this detached part of your figure, draw two wings, extending as far as the counterscarp.



The crownwork may also have a ravelin before each front of it, such as you drew to your hornwork; and it has its ditches, covered way, and glacis.

As the nature of the ravelins, &c. may easily be understood, you will draw the ditches of your crownwork only.

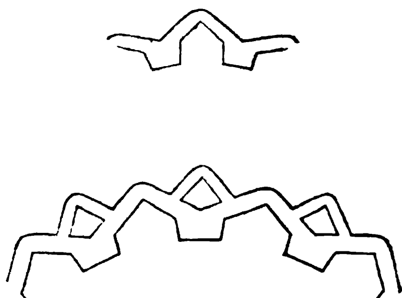


The wings of the horn and crownworks, which we have hitherto

drawn, are directed upon, and flanked by, the bastions of the body of the place.

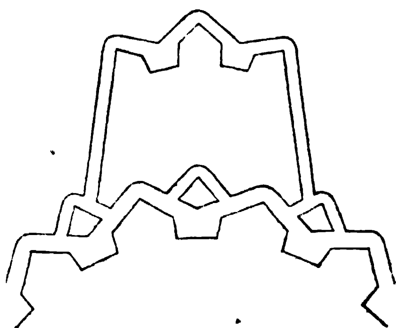
This is not however always done, the wings of these works being sometimes directed, not on the body of the place, but on ravelins or other outworks.

To exemplify this last described method, rub out the wings of your crownwork, with their ditches.



Draw ravelins to that part of your figure, which represents a portion of the body of the place; and draw also the ditches of these ravelins.

This being done, and the front of your crownwork still remaining as before; draw new wings to it, in the direction of the inward faces of the two extreme ravelins of your figure.



That is to say, draw the left wing of your crownwork, in the direction of the right face of your left ravelin; and draw the right wing of your crownwork, in the direction of the left face of your right ravelin: and complete your figure, by drawing the ditches of these new wings, in the usual manner.

Hornworks and crownworks have been distinguished by different names, according to the relative direction of their wings.

For instance, when the two wings of these works are parallel to each other, they are called parallel-sided.

The first hornwork, which I drew, was therefore A PARALLEL-SIDED HORNWORK.

When the wings diverge towards the rear, so as to become more and more distant from each other, the farther they are produced backwards, then the work is said to be diverging.

For instance, the crownwork in our present figure is A DIVERGING CROWNWORK, as you may observe by inspecting the direction of the wings.

On the contrary, when the wings converge towards the rear, so that if produced in that direction, they would meet in an angle, somewhere towards the interior of the fortress; then the work is said to be converging.

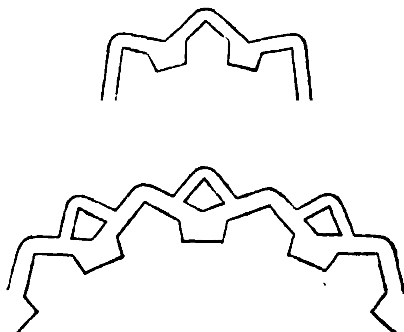
For instance, the first crownwork, which we drew, whose wings were directed upon the faces of two bastions, was A CONVERGING CROWNWORK.

Horn and crownworks are sometimes advanced beyond the glacis of a fortress.

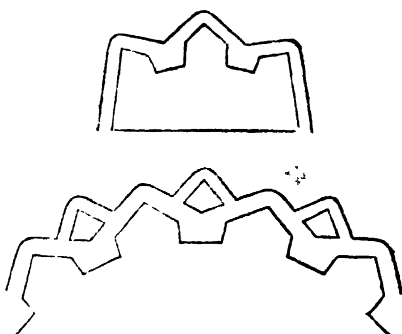
We shall change our present crownwork into AN ADVANCED CROWNWORK.

Rub out about one half of each wing of your crownwork, namely that half of each, which is nearest to the body of the place.

Rub out also the opposite counterscarps.



Connect the extremities of the wings, after thus reducing them, by a right line; which being done, the outline of your advanced crownwork will be complete.

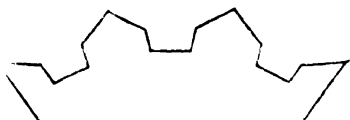


The entrance of an advanced work is usually made near the center of the gorge or reverse of the work; which should be of a respectable height, and reveted, in order to prevent an enemy from penetrating there. The reverse of such works, particularly when extensive, is not always laid out in one continued right line, as is represented in our present figure, but may be formed in any other mode judged convenient; as for example, with small flanks like a front of fortification. It may be crowned by a crenneled brick wall for musquetry, and may be strengthened by palisades, fraises, &c. if necessary; but should not, on any account, have a proper cannon proof parapet, because this, if constructed in the reverse of any advanced work, would be prejudicial to the defence of a fortress, by affording complete protection to the besieger's troops, after taking the said work, against the fire of the main inclosure.

The communication to an advanced crownwork may be formed, either by extending backwards the branches of the covered way of its two wings, until they unite with the main covered way of the fortress; or by means of a traversed caponier, cut through the glacis of the fortress, and leading from thence to the reverse of the crownwork, in a manner which shall hereafter be explained. A subterraneous gallery may likewise be used, for the same purpose, particularly if the distance beyond the glacis is inconsiderable.

Our present crownwork has only one bastion and two demi-bastions. If a work, similar to it in other respects, were constructed, but of so much greater extent, as to require two central bastions instead of one, then this new work would be called a double crownwork.

On another part of your paper, draw a sketch of A DOUBLE CROWNWORK; and let the wings of this double



crownwork be converging, in order to exemplify the last definition, a second time.

If a work similar to the above were constructed with demibastions and wings, at its extremities, but with three central bastions instead of two, then it would be called A TRIPLE CROWNWORK.

To recapitulate: there are three kinds of horn and crownworks.

1st. Those whose wings terminate upon, and are flanked by the faces of the bastions of the main inclosure: these are reckoned the worst.

2dly. Those whose wings terminate in the ravelins or outworks situated beyond the main ditch: these are reckoned better than the former.

3dly. Those which are advanced beyond the foot of the glacis. This last kind are reckoned the best, provided that their gorges are well secured.

The reasons, which have been assigned for this preference, are as follows.

When, according to the first supposition, the wings of the above works terminate upon bastions, the ditches of the said wings will form openings, by means of which the faces of these bastions are exposed to be breached, as soon as an enemy shall have effected his lodgement, and established batteries, on the crest of the glacis of the horn or crownwork. Thus the body of the place may be

laid open to an assault, at an early period of the siege, which must of course be a great disadvantage.

On the other hand, if, according to the second supposition, the wings are directed upon ravelins, then the faces of these ravelins will of course be exposed to be breached, by means of similar openings, at the same period of the siege, and under the same circumstances, before alluded to. This, although disadvantageous to the defence, will be less so than the former case.* But if, according to the third supposition, a horn or crownwork is advanced beyond the glacis, then the possession of such a work will not afford to the besiegers, any means of breaching either the ravelins or bastions of the main inclosure, they being completely covered by the intervening glacis, in which no openings are formed, when this construction is followed.

Horn and crownworks have generally been added to a fortress, for the purpose of occupying some important piece of ground, which either from motives of economy or from other circumstances, was not included within the limits of the original plan. The exterior sides of these works were, in former times, usually made much shorter than those of the body of the place; but recently, it has been judged best to make them equal, in length, to the latter, or nearly so. The interior of horn or crownworks may be retrenched to advantage, in a variety of different ways, as may easily be conceived; but having said so much upon the subject of retrenchments in a former chapter, it would be superfluous to give any new examples here.

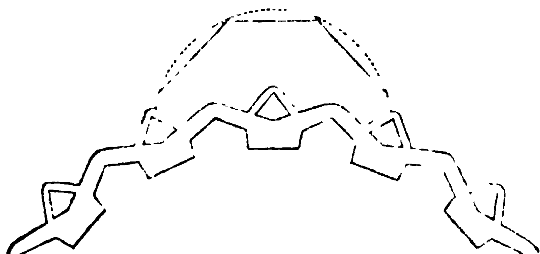
* In like manner, between the counterguards of the bastions and ravelin represented in the 6th figure of this chapter (*See page* 419), openings are formed, whereby the faces of the ravelin may be breached from the crest of the glacis. This is a much better disposition of the above counterguards, than if they had been so constructed, as to leave openings exposing the faces (not of the ravelins, but) of the bastions.

A kind of crownwork may also be constructed without wings: that is to say, the demibastions, forming its right and left extremities, may be closely connected with, or attached to, the ditches of the body of the place, whilst the central fronts of it may be more advanced.

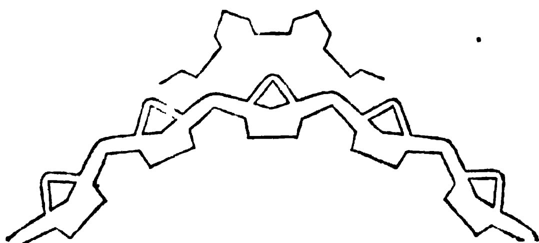
Draw five fronts of fortification, in outline, with ravelins and counterscarps, to represent part of a regular fortress.

With any convenient radius, draw an arc of a circle, between the salient angles of your second and fourth ravelins; let the middle part of it extend outwards, beyond the proper position for the glacis of your figure; and dot the said arc.

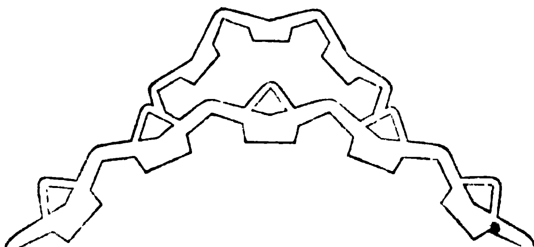
Upon this arc, mark two points, a little beyond the counterscarp of the above ravelins; divide the space between these points into three equal parts: and connect them by right lines.



These three right lines may represent the exterior sides of a polygon to be regularly fortified: draw three fronts of fortification accordingly, which being done, rub out the said lines as well as your original arc.



The form of a double crownwork now remains. Connect the extremities of it to the counterscarp of the nearest ravelins by short faces: and draw the ditches of the new work, thus formed, in the usual manner.



A double crownwork without wings, attached to the body of the place near each of its extremities, in the manner represented in our present figure, is called AN ATTACHED DOUBLE CROWNWORK.

Instead of constructing a continued crownwork, such as any of those which have been above described, for the purpose of fortifying an advanced position, it may sometimes be occupied to equal advantage, by a chain of detached works, not unlike a common crownwork in their general form, and of the same extent nearly.

This method may be understood, by supposing three or four detached lunettes to be constructed, of about the same size, and at the same intervals apart, as regular bastions. These may be secured in front, by a general ditch, covered way, and glacis: but they are not to be connected by any continued curtains. Intermediate tenails, or low curtains, separated from the flanks of the adjoining lunettes by a ditch, may however be used.

When three detached lunettes, connected as above described, are employed for the purpose of occupying any advanced spot of ground, the line of defence, thus formed, is called A BROKEN CROWNWORK. If two lunettes only of the above description are used, they will form what is called A BROKEN HORNWORK:

but if four are used, they will constitute A BROKEN DOUBLE CROWNWORK; and so on.

From what has just been said, it will readily be understood, that broken horn or crownworks exactly resemble the detached bastions and tenails, of the tower bastion system of fortification; so much so, that in a former figure, which was drawn to exemplify that system (*See the second figure of page* 349), if the tower bastions and curtains of the main inclosure were rubbed out, the exact representation of a broken double crownwork would remain.

Some authors prefer broken to continued crownworks, by reason, that in the latter, the capture of one bastion generally gives the enemy the command of the whole work; which effect does not follow when any part of a broken crownwork is taken.

We shall next proceed to the consideration of such advanced works, as have not hitherto been described; the most common of which are fleches and lunettes.

A FLECHE is a small work consisting of two faces only.

Draw a fleche.



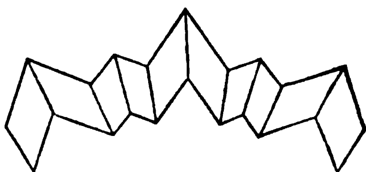
The fleche is usually placed close to the foot of the glacis, in front of and parallel to one of the salient angles.

A lunette generally has five sides, namely two faces, two small flanks and a gorge: consequently it nearly resembles the form of a bastion, or of a ravelin with flanks.

Draw a lunette accordingly.

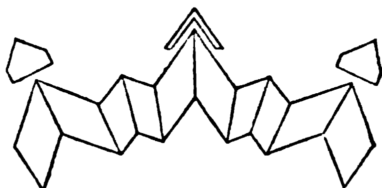


The lunette is also usually placed near the foot of the glacis, the capital of it being made to correspond with the produced capital of one of the places of arms.



In order to exemplify the manner, in which the works, that have just been described, may be situated, you will draw two sets of parallel lines to represent part of the glacis of a regular fortress; and connect the opposite angles of the figure, thus formed, by right lines, to show the ridges and furrows.

This being done, draw a fleche, near the foot of the glacis, in front of the center salient place of arms.

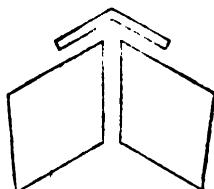


Draw also two lunettes, near the foot of the glacis, in front of each of the two other salient places of arms, represented in your figure.

The communication to advanced works is sometimes formed by means of galleries, and sometimes by caponiers, as was before mentioned.

These caponiers generally lead, in a direct line, along the produced capitals of the places of arms.

Draw on a larger scale part of a glacis, with a fleche in front of it.

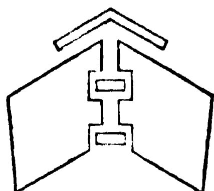


This being done, rub out the ridge of the glacis, which is immediately in rear of your fleche; and draw two parallel lines, in lieu of it, to represent the double parapet of your proposed caponier.

When a caponier extends any considerable length, as is represented in our present figure, it is usual to construct traverses, at certain intervals, to prevent it from being enfiladed.

Draw therefore two rectangles, extending the whole breadth of your caponier, or rather more, in length, in order to represent tra-

verses, placing the back of the retired traverse near the crest of the glacis.



We shall suppose each of these to be a disengaged traverse.

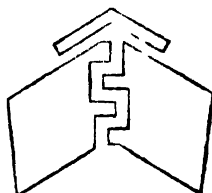
Draw a square passage, accordingly, at each extremity of your traverses, and rub out superfluous lines.

The form of A CAPONIER OF COMMUNICATION, extending across the glacis, is now complete.

Disengaged traverses, constructed in the manner represented in our present figure, between any double parapet, are called TAMBOUR TRAVERSES.

It is to be remarked, that caponiers or other open communications, of a similar nature, are not always formed with tambour traverses, although this is the most common system. Sometimes they may be secured against enfilade by engaged traverses, proceeding alternately from the right and left, so that the communication, thus protected, is of a serpentine form.

Engaged traverses, such as have been described, which proceed alternately from the right and left sides of a caponier, or other work, are called LOCK TRAVERSES.



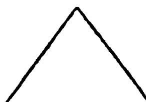
In order to exemplify this construction, rub out your present caponier, and its tambour traverses; and draw a new caponier of communication with lock traverses, in lieu of it.*

* Lock traverses are seldom used in permanent works, and therefore were introduced here, chiefly for the purpose of defining them. When traverses are required on a road or causeway, which it is not proper to block up entirely, these are the best that can be used. They are also the best adapted for securing, what is called, the double sap in a siege.

It is to be remarked, that one disadvantage ultimately attends all traversed caponiers. After the advanced work, to which they lead, is taken, they afford a ready-made communication across the glacis, or, as it is styled in offensive operations, an approach, almost equally convenient to the besiegers.

Besides fleches, and lunettes, works called redans are also sometimes constructed, near the foot of the glacis of a fortress.

The term REDAN, when applied to an independent or advanced work, denotes one which has two faces and a gorge, and which consequently differs only from a fleche, in its greater interior capacity. The outline of AN ADVANCED REDAN is as follows.



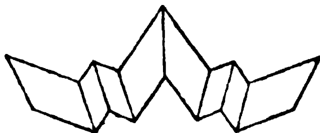
Fleches and redans, but particularly the former, usually resemble fieldworks in their construction: whereas lunettes are generally of a respectable relief, and built in a permanent manner, with proper revetments and ditches, and sometimes even with a covered way. Countermines have likewise, in some cases, been formed in order to strengthen them, as also crenneled counterscarp galleries, to protect them by a reverse fire against an assault.* With respect to the proper mode of securing the gorges of lunettes, the same remarks apply, which were before made, in speaking of advanced horn and crownworks.

Sometimes, but particularly in marshy situations, a fortress may have an advanced ditch.

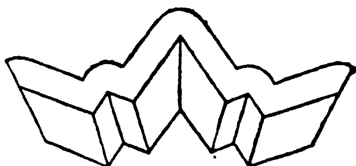
The advanced ditch is situated beyond the foot of the glacis of the fortress.

* The advanced lunettes of St. Philip's Castle, in Minorca, were secured in this manner; and communicated with the works of the fortress in rear of them, by galleries cut out of the rock.

Rub out the fleche, and the two lunettes, that you drew in front of your former figure, which represented part of the glacis of a fortress.

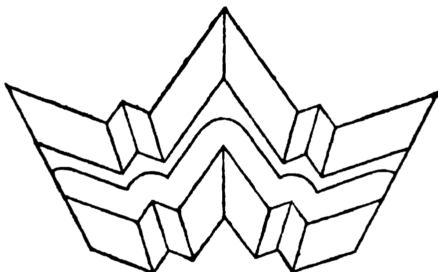


In front of, and parallel to, all the lines of the foot of your glacis, draw a second set of lines, to represent the counterscarp of your advanced ditch, making, however, all the salient parts circular, according to the rule followed in drawing the ditches of ravelins, &c.



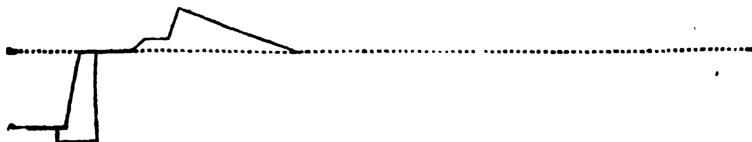
An advanced ditch usually has also an advanced covered way, and glacis, in front of it.

Draw an advanced covered way and glacis, in front of your present figure.



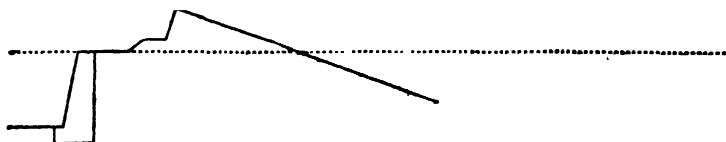
In making an advanced ditch, the interior side or reverse of it is generally formed, by continuing the slope of the glacis; but the exterior side or counterscarp of it may be reveted.

To exemplify this by proper figures, you will first draw the section of a common covered way and glacis; dotting the ground line.

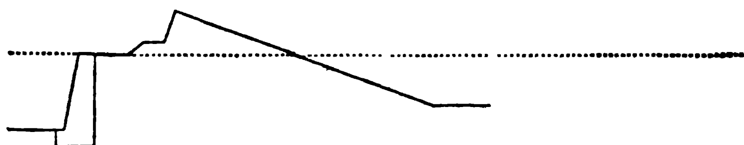


This being done, produce the slope of the glacis to a sufficient

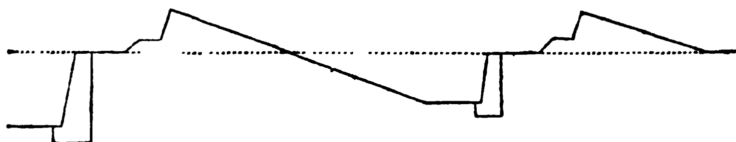
extent below the ground line, in order to show the proposed depth of the advanced ditch.



From thence draw a horizontal line, outwards, to show the breadth of the advanced ditch at bottom.



Construct the counterscarp revetment of your advanced ditch, in the usual manner, beyond which you will also construct an advanced covered way and glacis.



It was before stated, that the gorge of every advanced work is usually reveted, in order to prevent an enemy from penetrating by the reverse of the work. These revetments have ditches in rear of them.

The section of the ditch, in rear of an advanced work, is generally made similar to the section of the advanced ditch in our present figure, the reverse side of it being formed, so as to coincide with the slope of the glacis produced. Provided that this rule is attended to, an enemy, in attacking an advanced work by the rear, will not be covered any where against the guns of the fortress; for shot, fired along the slope of the glacis, will be able to strike him in every part of the above ditch.

If, on the contrary, the ditch, in rear of an advanced work, were not formed with a very gentle reverse slope, as above described, but were either reveted, or constructed with a steep earthen slope, on that side; then the enemy, both in attacking the work, and in maintaining possession of it, would be screened, in the said ditch, against the fire of the place.

It is to be observed, however, that the reverse of a small work, such as a lunette, &c. if constructed with a ditch, steep in rear, yields very little cover to an enemy, in comparison with that, which would be afforded by a large horn or crownwork, under the same circumstances: and therefore, since ditches steep on both sides are certainly much the strongest against an assault; it may often be expedient to make use of them, in reverse of the former kind of work, although, in the latter, they might be objectionable.

A ditch, formed with a very gentle slope in rear, is called A HA-HA DITCH, in order to distinguish it from a common ditch, which is steep in rear as well as in front. The reverse of a ha-ha ditch, being laid out in the above described form, solely in order to prevent an enemy from obtaining cover; it will be obvious, that when a ditch of this description is partly filled with water, the gentle slope need not be continued much lower than the surface. Beneath that level, the reverse of the ditch may either be reveted, or formed with an earthen slope of about 1½ times its height.

Detached works, constructed for the purpose of strengthening a fortress, may either consist of forts or redouts.

The term fort implies a small fortress. Thus for example, in polygons fortified according to the bastionary system, the square or pentagon would be called A FORT, whilst the nonagon, decagon, &c. would be styled fortresses.

A work, nearly equal in extent to the bastionary square or pentagon, if constructed according to the redan system, is called A STAR FORT.

Any other inclosed work, which is 800 yards or upwards in circuit, so that it is either nearly equal to, or greater, in extent, than a common bastionary square, is also styled a fort, notwithstanding that the outline of it may be very irregular.

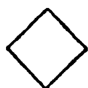
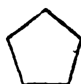
When fortified in a temporary manner, such a work would be called a FIELD FORT.

A redout signifies an inclosed work, usually of small extent, that is to say, scarcely ever exceeding 300, or, at the utmost, 400 yards, in circuit: and having no regular flanks, but presenting a ditch and parapet in every direction.

It will readily be understood, that a redout, as above defined, is much too small a work to be capable of being applied to any general purpose of defence, singly or independently. And therefore, when any piece of ground is to be fortified by redouts, they must be distributed along the whole extent of it, at such distances apart, as to be able to support each other, by their mutual fire, like the adjoining bastions of a fortress. This constitutes, what is called, A CHAIN OF REDOUTS; and the same term is also applied to a number of detached works, of any other description, if distributed in a similar manner.

Redouts may either be quadrilateral, pentagonal, or in the form of any other small polygon, regular or irregular, that is judged convenient.

Draw some redouts of various forms, in order to exemplify the foregoing definitions.

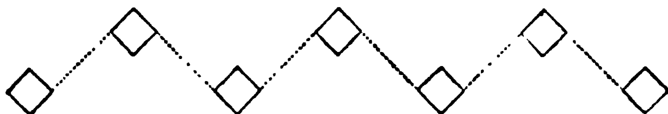
   

Redouts may also be curved, in a part or in the whole of their outline; the principal object being to suit them to the nature of the ground, when that is irregular; and in this case, not only their form, but also their intervals, may vary according to circumstances.

If, on the contrary, a piece of ground is quite regular, then the redouts, constructed for the purpose of fortifying it, may all be made of the same uniform figure, and placed at equal intervals apart.

Sometimes A DOUBLE CHAIN OF REDOUTS is used, in which case, they are almost always chequered, that is to say, the redouts of the second line are placed opposite to the intervals between those of the first line.

To exemplify this disposition, you will draw a double chain of quadrilateral redouts, consisting of seven in all, three of which you will place in the advanced line, and the remaining four in the retired line; and let the latter be so disposed, as to flank the salient angles or faces of the former, in the manner represented by the dotted lines in the annexed figure.*



It is to be remarked, that when a double chain of redouts is used, the reverse parapets of the advanced line of redouts should only be musquet proof.

The quadrilateral form, represented in our present figure, is often applied to redouts, constructed in regular ground, but that of lunettes or flat bastions is also no less common, and may be considered better than the former.

It is desirable, in forming a chain of redouts, that they should not be placed at intervals of more than from 400 to 600 yards apart; the former distance being preferable. In a chain of forts, which

* A double chain of advanced lunettes, in front of a glacis, has also been recommended by some authors, the exterior line of lunettes being supposed to be placed in the allinement of the produced capitals of the ravelins, the others before the bastions, of the fortress.

require each a regular siege, the intervals, not measured from center to center, but between the foot of the glacis of any two adjoining forts, may without inconvenience be 1500 yards or even more.

Redouts are in very common use in field fortification. When applied to permanent purposes, they should be reveted and have a respectable relief.

PERMANENT REDOUTS are also styled CASEMATED REDOUTS, bombproof cover being so indispensably necessary in these works, that they are never constructed, without casemating some part of them. They sometimes, also, have a covered way, crenneled galleries, countermines, &c. and a portion of them is frequently retrenched to serve as a keep.* The faces of permanent redouts should be large enough, to admit of a respectable number of heavy guns being placed in battery, otherwise such works will be of little use: † and the same remark holds equally good, in respect to the lunettes, which were before described.

* A loopholed tower has been recommended for that purpose, not only in detached works, but also in advanced works, and in this latter case it must only be musquet proof, on the reverse side of it.

† As a specimen of the nature of a casemated redout, which has actually been executed, a description of Fort Tigné in the island of Malta is added, to the best of my recollection, for I have no accurate plan or measurements of it.

This work is of a quadrilateral figure, the length of the sides not exceeding 85 yards. The scarp is about 30 feet high, and casemated, with loopholes, for firing into the ditch. The parapets are of the soft free stone peculiar to Malta, and are pierced with embrasures for cannon, at rather more than the usual intervals apart, covered over at top, interiorly, with large stones, and having intermediate banquettes formed with steps of masonry. In the direction of the capital of the work, which presents a salient angle towards the country, there is a casemated barrack, equal in height to the terrepleins, with which it communicates, and having loopholes for musquetry on each side of it. Immediately in rear of this, that is to

A chain of redouts or other detached works may be connected by a continued covered way, which in this case is not supposed to be always kept completely manned, so as to resist an attack by main force, like that of a regular fortress; and therefore is neither reveted in front, nor palisaded, being merely intended to afford a secure communication, between the various detached works, so long as the enemy is employed in erecting his batteries, or in other distant operations, preparatory to an actual assault.

A chain of detached forts, redouts, &c. is peculiarly well calculated for the purpose of keeping an enemy at such a distance from a fortified dockyard, or great arsenal, as to render it impracticable for him to destroy the public buildings and stores, by bombardment; an object, which otherwise might be carried into effect, in a very short time after an unexpected disembarkation, even in the face of the strongest fortress. For it may easily be understood, that although the reduction of the various works of a well con-

say, in the reverse angle of the redout, there is a round tower, serving as a keep, which is about 35 feet high, and 60 feet in diameter. It is built with two stories, and has two tiers of loopholes, pierced in its exterior walls, which are about 4 feet 6 inches thick. It has a terrace, and stone parapet at top, to which there is a communication by means of winding staircases. The entrance to the tower is by a drawbridge. A palisaded caponier, in rear of it, leads at a short distance to the harbour of Marsamuscet, beyond which this redout is situated, as an advanced work to the famous fortress of Valetta. It has a good ditch and reveted counterscarp, and countermines, proceeding from a counterscarp gallery, three portions of which, namely those which are near the advanced angles of the redout, project backwards into the ditch, being made more spacious than the rest of it, and are constructed with loopholes, to produce a reverse and flanking fire of musquetry, as also with airholes, at certain intervals, to carry off the smoke in firing. These galleries, as well as the countermines, are connected with the interior of the redout, by communication galleries, sunk beneath the level of the ditch. There is a kind of covered way, not continued all round in the usual manner, but in three portions only, which are over the principal crenneled galleries of the counterscarp; beyond which follows the glacis.

structed and well defended fortress, by a regular siege, is an enterprise of great labour, hazard, and difficulty, and not to be accomplished under a certain number of weeks, or even months; yet, if there are no detached works to cover it, the mere process of firing a vast number of shells, red hot shot, and rockets, into the interior of it, which must necessarily destroy every thing combustible that they meet with, may be performed in a few days, and with little or no risk on the part of the assailants. An enemy, who may not have the means of regularly besieging a fortified naval arsenal, nor the power of maintaining permanent possession of it, should it from any circumstances fall into his hands, may therefore often be tempted to embrace an opportunity of suddenly destroying such an establishment, by bombardment, when he knows that it is destitute of an exterior chain of defensive works.

CHAP. XXI.

OF THE MODE OF DEFILADING COMMANDED WORKS.—THE NATURE AND USE OF MODELLING PLANS EXPLAINED.

In choosing a situation for a fortress, it is always desirable, that no part of the ground, which is to be occupied thereby, should be commanded by any higher ground, within the distance of about 1000 yards from the proposed works. This, however, is not always practicable; for cities, harbours, passes, &c. may be of such great importance, in a general view, to the defence of a state, as to render it absolutely necessary, that they should be fortified, although commanded, on one or more sides, by exterior heights.

Those works of a fortress, which have higher ground in front of them, are not liable to be much more injured by a direct fire of cannon, than if they were not so commanded: but from the angular form which is given to all the outlines, in modern fortifica-

tion, if the commanding exterior heights are of any considerable extent, it will be obvious, that some part of the faces of the various works cannot fail to be exposed to an enfilading or reverse fire of artillery from thence; and when such is the case, a commanded work labours under a very great disadvantage.

To exemplify this by a figure, draw a horizontal line, A B, upon which, as a ground line, construct the sections of the two opposite faces of a reveted quadrilateral redout, and on one side only, namely that which is towards the right of your ground line, construct a ditch, covered way, and glacis, also in section, in the usual manner.

Let the two faces of the redout, which are seen in section, be of the same profile and relief: mark the crest of the parapet of the right face by the numeral figure, 1, and that of the left face by the numeral figure, 2. Connect these points by a right line: connect also, in like manner, those two points in each section, which represent the foot of the interior slope of the parapet; and dot the superfluous parts of your original ground line.

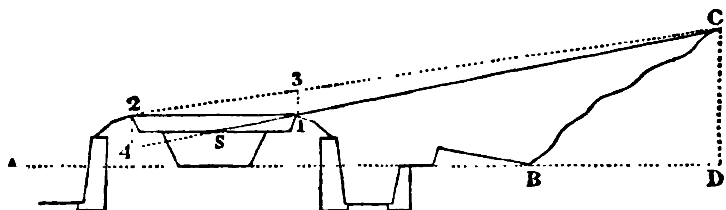
This being done, your figure will show, not only the sections of two opposite faces or sides of the redout, but also the elevation of one of the other adjoining sides of it, of which the line, comprehended between the points, 1 and 2, represents the extent of the interior crest of the parapet.

Let us suppose, that the work, which we have just drawn, is situated at the foot of a commanding height. In order to exemplify this circumstance, from the point, B, beyond the foot of your glacis, draw a line, B C, to represent the section of the height, in outline; and from the highest point, C, drop a vertical line, C D, meeting the horizontal line, A B, produced, in order to show the superiority, or difference of level, of the commanding ground.

This being done, from the point, C, draw a right line, C 1, and

produce it, until it meets the level of the terreplein of the redout in the point, s.

The dotted lines, C 2, s 4, 1 3, *and* 2 4, *have been added to the figure, although not specified in the foregoing directions, for a reason which shall hereafter be explained.*



By inspecting the figure, it will now appear, that a shot fired from a gun, placed in battery on the commanding height at C, with a full charge of powder, and with just sufficient elevation to clear the nearest point, 1, of the crest of the parapet of the redout, will plunge into the terreplein of the enfiladed face, 1 2, which is seen in elevation, somewhere near the point, s.

Consequently, as troops posted on the terreplein of the face of any work, so enfiladed, could derive no protection whatever from the parapets, excepting in a certain portion of the extent only; it follows, that they would neither be able to line the banquettes, nor to stand to their guns, but must, in a short time, abandon the exposed parts of these enfiladed faces, entirely, in order to shelter themselves from the destructive effects of the enemy's artillery.

The rear face of the redout, represented in our present figure, the crest of the parapet of which is marked by the figure 2, is still more exposed; there being no part whatever of the terreplein of it, which is not completely seen into, in reverse, from the artillery, supposed to be placed on the commanding height, C.

In short, in no face whatever of the redout, are the men posted on the terreplein properly protected, excepting in the advanced

face of it, the crest of the parapet of which is denoted by the figure, 1; and the superior security, which this face therefore possesses, in comparison with other parts of the redout, proceeds entirely from the circumstance, of its being exposed to a direct fire, only.

When the face of any work can be completely plunged into by an enfilading fire from a commanding height, like the face, 1 2, in our present figure, it will be evident, that nothing but the construction of a certain number of high traverses, at proper intervals, can give a due security to the men posted upon the terreplein of the said face.

But when it is entirely seen into, in reverse, like the rear face of our redout, then traverses will be ineffectual, and the only mode of securing the men posted there, will be to cover them by a second parapet, of proper height and thickness, constructed upon the rear of the terreplein; so that in working their guns, they will be posted between two parapets, as in a caponier.

A parapet, constructed in rear of any work, for the special purpose, which has just been stated, of covering men against a reverse fire, is called A BACK SCREEN OR PARADOS.

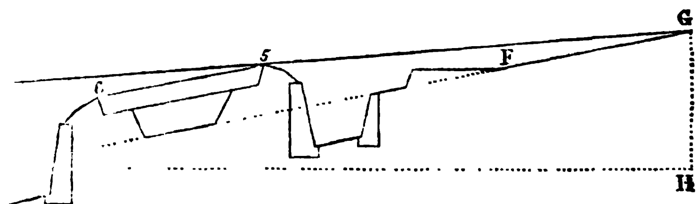
It is next to be observed, that a work, equal to our present redout in extent, and placed at an equal distance, from a height equally commanding, may not always be liable to be plunged into, in the same very disadvantageous manner.

To exemplify this remark by a new figure, draw a right line, E F G, to represent the side of a range of high ground, rising gradually in a regular inclined plane, and let the latter point, G, have the same command, G H, and at the same distance, over, E H, the level of the point, E, which the commanding point, C, had over, A, in your former figure.

This being done, on the space, E F, construct the section of a

work, nearly similar to that, which was constructed on the space, A B, in your former figure; giving to the revetments, parapets, &c. the same thickness, and to the terrepleins and interior area, as well as to the ditch, covered way, and glacis, the same breadth: give to every part of your new work also the same vertical relief above, or the same vertical depth below, the line, E F, which the corresponding parts of your former work had in respect to the line, A B. In short, the only difference in the profiles of your two redouts will be, that the profile of the first was constructed according to a horizontal ground line, whilst that of the second is laid out according to an oblique ground line.

You will next dot those parts of the line, E F, which will become superfluous, after your redout is drawn. Mark the crest of the parapet of the advanced face, by the numeral figure, 5, and that of the retired face, by the numeral figure, 6; and from the commanding point, G, draw a line, G 5, which you will produce to the point, s.



It will now be evident, from inspecting your present figure, that a shot fired from a gun, placed in battery on the commanding height at, G, with a full charge of powder, and with just sufficient elevation to clear the nearest point, 5, of the parapets of the redout, will not be able to plunge into any part of the terrepleins whatever, either by an enfilading or reverse fire, but will go clear over the whole work in the direction, s. Consequently, in our present redout, men will be properly covered by the parapets, throughout every part of it.

When the reliefs of any face of a work, such as, 5 6, of our present figure, are so regulated, that, although commanded, it cannot be seen into, it is called a defiladed face; and the right line, 5 6, which marks the crest of the parapet of it, is called A DEFILADED LINE.

The right line, G 5 s, drawn from the commanding height, through the highest point of the nearest part of the commanded work, is called THE LINE OF DEFILADE; because every other more distant part of the work, which is beneath that level, will be defiladed, or covered against a plunging fire: whereas, if any of the other parts were above that level, they would be seen into.

By comparing attentively the two figures, which you have last drawn, it will appear evident, that the great advantage, which our present redout has in not being plunged into, like the former, arises entirely from the circumstance, of its profiles being constructed, not according to a horizontal ground line but an oblique one.

The ground line of a section, being the most useful line in determining the various reliefs of any proposed works, is also styled the regulating line.

In the former chapters of this book, we have invariably supposed the surface of the ground, on which any work was situated, to be an uniform horizontal plane, so that the natural level of the ground formed also the most convenient regulating line, for the purposes of construction.

It will, however, be readily understood, that if the ground, on which any work was about to be built, although generally speaking nearly horizontal, were found to have various inequalities, rising in some parts and falling in others, above the mean level; then the outline of the natural surface, being of a curved irregular form, would be entirely unsuitable for THE REGULATING LINE OF A SECTION. It would consequently be necessary to assume

the mean level of the ground, instead of its actual outline, for the purpose in view.

In like manner, when the ground, upon which any proposed work is to be built, slopes according to an inclined plane of uniform rise; it may often be convenient to use THE NATURAL GROUND LINE, as the regulating line of a section, according to the system followed in drawing our last figure: but when the surface is not only oblique to the horizon, in its general direction, but is also broken and irregular in its outline; then A CORRECTED GROUND LINE must necessarily be used in lieu of it.

And even when the surface is perfectly regular, the same expedient may often be necessary, as was proved by the first redout that we drew, in which a great part of the interior of the work is completely plunged into.

This was entirely occasioned by using the natural horizontal surface, for the regulating line of the profiles of that redout; instead of assuming a corrected ground line in an oblique direction, in lieu of it, for the same purpose; which, if it had been done judiciously, might have given the various faces a proper defilade, like those of our last figure.

It is to be observed, that in choosing a corrected ground line, it is always desirable, that it should vary as little from the mean level or outline of the natural surface, as circumstances will permit.

But before a corrected ground line, or regulating line, can conveniently be chosen, for the purpose of planning the reliefs of a commanded work, a defiladed line must first be found, passing at a certain height above the surface, in order to determine the comparative levels of the various parapets, in such a manner, that no part of the terrepleins shall be plunged into. This being done, the regulating line must be drawn parallel to the above line of defilade, at any convenient distance below it, taking care, however, to adhere

to the rule, which was just before stated, in respect to its general level or outline.

To exemplify this remark, by referring once more to our first section, (*see the figure in page* 445) it will be evident, that the dotted lines, 3 2, and 1 4, are both defiladed lines. Consequently if the crest of the parapet, 1, were raised to the level, 3, those faces of the redout, which are at present exposed both to an enfilading and reverse fire, would no longer be seen into. If such, therefore, were reckoned a proper height, then a regulating line might be chosen at any convenient distance below it, as for example at the distance of 20 feet, measured vertically; which being accordingly drawn parallel to 3 2, at the above interval, the relief of the glacis, and the depth of the ditches, might be determined thereby, in the usual manner.

Again, if instead of raising the advanced parapet, 1, the retired parapet, 2, were lowered to the level of the point, 3, then the same effect of defilading the various faces would be obtained, and a regulating line might also be found, in a similar manner.

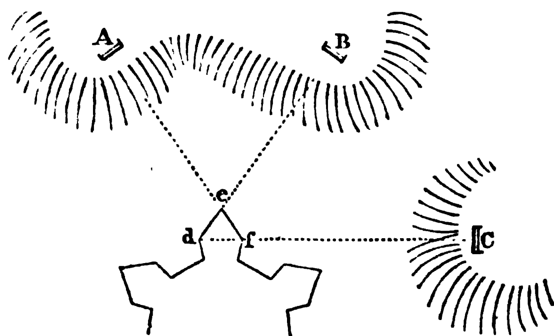
If on the other hand it were judged better to adopt a medium height instead of either of the lines, 3 2, or 1 4; then the advanced parapet, 1, might be raised half way up to the point, 3, and the retired parapet, 2, might be lowered half way down to the point, 4. This also would defilade the faces of the redout, and by using this method, the works would be neither too elevated nor too much depressed, so that a regulating line, more nearly agreeing with the medium level of the original ground, would thereby be obtained.

It may appear almost superfluous to explain, that a line in a section may often represent a plane. Thus for example, in regular fortification on level ground, the common ground line represents the horizontal plane, which is formed by the natural surface. And, in like manner, when the surface is irregular, the corrected ground

line, or regulating line of a section, represents what is called the regulating ground plane of the work.

Consequently, in speaking of the actual construction of a redout, bastion, or other work, the terms, PLANE OF DEFILADE, DEFILADED PLANE, REGULATING GROUND PLANE, or as it sometimes is simply called REGULATING PLANE, are more commonly used than the corresponding terms, "line of defilade," "defiladed line," and "regulating line," which apply more peculiarly to the section only.

When a fortress is constructed opposite to a range of commanding heights, extending in the same uniform direction, or nearly so, according to a right line, the faces may easily be defiladed, in the manner which has been described; but when it is surrounded by heights on more sides than one, then the object of defilading the various works becomes a subject of much intricacy, which is often not to be accomplished by any disposition of the general reliefs whatever; so that traverses and parados must necessarily be resorted to.



For example, if we suppose the three bastions, &c. shown in the annexed figure, to represent part of a regular fortress, commanded by one height only, extending in a right line, upon which are two enfilading batteries, A and B, it will be evident, that the face, e d, may be defiladed, so as not to be plunged into from the height, K

by making the extremity, d, some feet lower than e: and the face, e f, may be defiladed so as not to be plunged into from the battery at A, by making the extremity, f, also some feet lower than e; and in like manner, any other works whatever on the low ground, may be defiladed from any other points whatever of the above range of heights: and if the ground at C, were lower than the situation of the fortress, no inconvenience whatever would arise from thus regulating the reliefs of the two faces, d e, and, e f.

But if we suppose the ground at C, also to have a considerable command, then the point, f, by being reduced in height, for the purpose of defilading the face, e f, from the enfilading fire of A, will lead to the very serious disadvantage of exposing the left face and left flank of the bastion to be plunged into, by a reverse fire, from the battery, C: for unless the point, f, is high, it must be evident that the point, d, cannot possibly be covered in rear. Hence is proved, what I before asserted, that a proper defilade, against commanding heights, bearing upon a work in contrary directions, is impracticable; for the defilading of any part of the work against the one height, will only cause it to be so much the more seen into, from the other.

It is to be remarked, that when a cavalier bastion is commanded in this peculiarly disadvantageous manner, the faces and flanks of the cavalier may effectually serve as parados, to screen the corresponding parts of its inclosing bastion, against the reverse fire of the commanding heights.

As for the cavalier itself, by reason of its smaller interior space, a high substantial traverse, constructed nearly in the direction of its capital, may answer the same purpose.

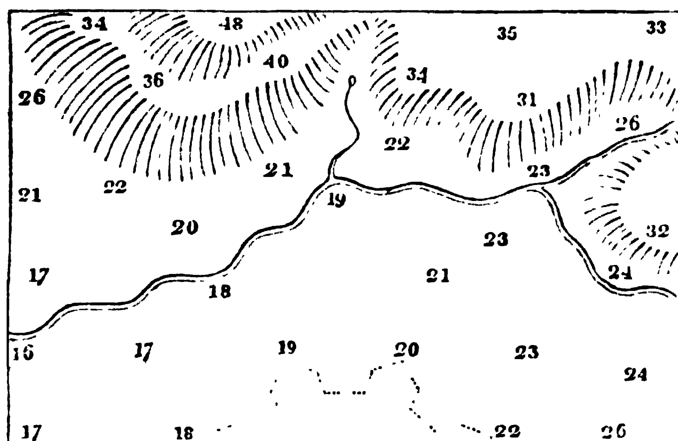
This kind of traverse, which is very commonly used in small works, is called A CAPITAL TRAVERSE.

Each of Vauban's tower bastions, for example, had a traverse of this description.

It was before explained, that when a fortress is situated on a horizontal plain, the same general profile applies to all the corresponding parts, and the ground lines or regulating lines of every section, that can be taken, are all exactly on the same level, so that two or three very simple sections will suffice to give a just notion of the whole of the reliefs of the various works. But when a fortress is situated on irregular ground, and is moreover commanded on one or more sides, so as to require the works to be defiladed, it must be evident, that there can be no general profile, for the reliefs of one front may be very different from those of another; and the regulating lines, according to which the various works are constructed, may also have been laid out according to very different levels and planes.

It was stated, in treating of the principles of plan drawing, that the nature of any work cannot be understood from a plan alone, without sections: but when ground is so very irregular, as has just been supposed, a multiplicity of sections, not reduced to any common level, might tend rather to confuse, than to give clear notions of the nature of it. A kind of plan has therefore been devised, which is capable of showing, not merely the form of the ground, as it usually appears in common plans, but also the reliefs of the various parts. This is done by taking a great number of levels, at divers points of the ground, so as to determine the height of these points above some general or master level, assumed for the purpose, which ought to be lower than any point actually included within the limits of the proposed plan. Thus, for example, if the ground to be fortified is near to the sea or to any harbour; the ordinary low water mark at spring tides may conveniently be chosen, as the master level for the plan in question. Then let the height of a sufficient number of points, above that level, be accurately found, by a proper instrument, and marked on the plan, in feet and inches, so as to dot over the surface of it with numbers, like the soundings in a naval chart, and the object in view will be attained.

A plan marked with levels, in the manner which has just been described, is called A MODELLING PLAN,* because by reason of its peculiar property, before mentioned, of shewing reliefs, which a common plan does not possess, it may serve as a substitute for a model: and indeed it is impossible to model any tract of ground properly, without previously taking an accurate plan of this description; the nature of which may be better understood from the annexed sketch. The dotted lines are supposed to represent the position of part of a proposed work of fortification.



To explain the use of a modelling plan, as applied to the pur-

* Modelling plans have long been in common use amongst the French engineers, but instead of choosing their master level below the surface of the ground to be fortified, they generally select some point above it, for that purpose. This appears to me a very injudicious method, because in a plan, so constructed, the lowest ground is invariably marked with the highest number of feet, which must tend to confusion, and, in calculation, may often lead to error. The method given in the text, occurred to me, when directed to draw up a project for fortifying some irregular ground in Malta; before I had seen a modelling plan, or knew that such an expedient had ever before been adopted. One French author (Mr. Bousmard) agrees in recommending, that a low master level should be assumed, contrary to the usual practice of his countrymen.

poses of fortification, let us suppose, that the spot chosen for the salient angle of a bastion of any proposed work, is marked by the number 20. This will denote that the corresponding point on the ground is 20 feet above the level of low water: and if within the distance of 800 yards measured by scale, there is no greater number than 20 to be found any where on the plan, it proves that the said bastion will not be commanded within that distance. If on the contrary, there should be any high number, such as 40, marked at 800 yards, then it proves, that at that distance there is a height, which has a command of 20 feet, over the spot on which it is proposed to place the salient angle of the bastion; the parapet of which must therefore be raised 20 feet higher than the natural ground, in order to put it on the same level with the commanding height.*

When the outline and reliefs of any proposed fortress are under consideration, the modelling plan, previously drawn, should include not only the ground which will be covered by the intended works, but also the surrounding country, to the distance of about 1000 yards all round; which being done, the proper height and defilade of any part of the intended works may be determined from such a

* In drawing a sketch of the position of an army, which ought also to show the ground in front within cannon shot; as the relative commands of the various heights are of great importance, it is usual to mark them by the numbers 1, 2, 3, &c. which, in this case, do not denote any precise dimension, but merely serve as a scale of comparison to enable the general, for whose use the sketch is made, to judge of the nature of the ground. Thus, for example, if the least number marked on the plan is 1, and the greater 10, it shows that the former is the lowest and the latter the most commanding part of the ground: and of the intermediate numbers, 5 denotes a height less elevated than 6, but higher than 3. In short, the principle of the military sketch and that of the modelling plan are precisely the same; but with this difference, that the former is a hasty performance, done according to the best of the judgment of the officer employed, without taking ỳ levels by an instrument, whereas the latter is strictly accurate in its minutest details.

plan almost by inspection. This might perhaps have been inferred, by reflecting upon what has already been said, without any further explanation.

I shall however for the sake of clearness add another example.

Let us suppose that it is proposed to make the salient angle of a bastion 24 feet high, above the natural level of the ground upon which it is to stand: and that, by a reference to the modelling plan, it appears that at the distance of 700 yards, there is a range of heights 28 feet higher, than the above part of the work will be, when complete. This gives a command, over the point of the bastion, in the proportion of exactly 4 feet in 100 yards. If therefore we suppose one of the faces of our bastion to be 100 yards long, and directed upon the above heights, it is evident, that it will be necessary to give the said face a dip or fall of four feet in its total length, in order to defilade it from the commanding ground. And consequently, if the ground, upon which the bastion is to be built, is nearly horizontal, the height of the bastion at the angle of the shoulder must be 20 feet above the natural ground.

I shall here remark, that the nature of the command, which one work or height may possess over another, cannot be explained with any precision, unless by reducing it to a certain proportion; for this proportion not only determines at once the proper defilade, but is also, in distances not much exceeding 600 or 700 yards, nearly an exact criterion of the disadvantage incurred by the commanded work, from cannon shot fired at full charges. At the same time in describing a command, the actual distance should never be omitted,* because in distant firing, in proportion as the effect

* Some authors have designated the nature of a command by the difference of level merely, without any reference to distance, calling 9 feet a single command, 18 feet a double command, &c. This is, however, a very inaccurate and indeed absurd mode of speaking, for it must be evident, that a double command, as they style it, at the distance of 50 yards, will be more prejudicial to a work than a quadruple command at 400.

of artillery is rendered uncertain by the greater length of range, the circumstance of a work's being commanded becomes of less importance, or may even be entirely disregarded.

It is to be observed, that shells from a mortar, being fired at a considerable elevation, always bury themselves in falling; whereas howitzer shells and cannon shot, being seldom or never fired with any great elevation, rise again, with repeated bounds, after they first meet the surface of the ground. But when full charges of powder are used, in firing, from a moderate distance, at any bastion, redoubt, &c. which is properly defiladed, the cannon balls, if they do not lodge themselves in the parapet, are impelled with so much velocity, that they fly entirely over the work; nor will they strike the ground until at a very considerable distance further, their original path being nearly in a right line. If, however, small charges only are used, the initial velocity of the shot being thereby much diminished, their ranges will be shortened in proportion: and they will describe a considerable curve in their flight, immediately after leaving the piece: and consequently, by this method of firing, provided that a proper elevation is given to the gun, a cannon ball may be pitched, over the flanking parapet, into the terreplein, even of a well defiladed face, where, by its successive bounds, it may do much injury.

The mode of firing, which has just been described, is called RICOCHET FIRING, and may be practised to advantage, both from guns and howitzers, whenever they can be placed in such a position as to enfilade any long face of a work. In direct firing, on the contrary, this method is not to be recommended, for the diminution of the charge produces a corresponding diminution in the effect of the shot.

It was proper to make the above explanation, in order that it might be fully understood, that the defilading of any face of a work, although of importance, inasmuch as it prevents it from being seen into, from a commanding height, does not entirely secure it,

against being plunged into by enfilading ricochet batteries; and therefore, in previously stating the advantages, derived from a proper defilade, as far as cannon shot were concerned, I took care always to specify, that full charges were supposed to be used.

To conclude this part of our subject, it must appear sufficiently obvious, from what has just been stated, that nothing but frequent traverses, one, for example, between every two or three guns at the utmost, can give any proper security to the faces, even of a well-defiladed work, against enfilading ricochet batteries.

CHAP. XXII.

OF IRREGULAR FORTIFICATION, CITADELS, AND COUNTERTRENCHMENTS.

It is a fundamental rule in fortification, to endeavour to make a place equally strong on all sides; for it must be evident, that it would be of very little use to have three fourths of the circuit of a fortress absolutely impregnable, if the remainder of it were weak and defenceless.

In teaching the principles of fortification, it is always usual to suppose, in the first instance, that the ground to be fortified is situated in the midst of an extensive level plain, uniform on every side, and not commanded by any heights within cannon shot.

Under this supposition, a regular polygon will, of course, be the best figure that can be adopted for the outline of a work, because it will be exactly alike, and therefore equally strong on all sides; and the exterior ground being likewise uniform all round, in every direction, an enemy can derive no advantage, in attacking from any one point in preference to others.

But although such a supposition is always assumed, as was before observed, in explaining the rules of fortification, this is

done, merely with a view to simplify the subject, and thereby to facilitate the progress of the learner: for in real practice it seldom or never happens, that ground can be chosen for the situation of a fortified place, so uniform in its nature, as to admit of the outline of the fortress being made perfectly regular.

Fortresses, for example, are often built upon the sea coast or on the banks of great rivers, the form of which must be followed; and the situation which is to be fortified, as well as its environs, may consist partly of low ground, and partly of heights, of an irregular form, with intersecting vallies. On one or more sides, also, it may be bounded by lakes, marshes, or rocky precipices.

Under these circumstances, it would obviously be improper to give to the outline of the proposed fortress the form of a regular polygon. Such an arrangement would lead to insuperable difficulties and disadvantages. It might, for instance, throw the ramparts down into the bottom of deep vallies, when they would be exposed to the plunging fire of a besieging army, from commanding heights, without the power of returning it with any effect.

The nature of the ground must therefore be carefully studied, and the strongest points chosen, for the general outline of the proposed fortress, which, when the ground is irregular, will consequently become an irregular polygon, instead of a regular one: and when the situation has the further disadvantage of being commanded by exterior heights, on one or more sides; then not only the outline, but also the profiles or reliefs, of the proposed works, must be made irregular, for the reasons stated in the preceding chapter, in which one great source of irregularity in fortification was discussed.

After choosing the most advantageous points for the outline of a fortress, it will often happen, that some parts of it are by nature

excessively strong, so as to require scarcely any artificial means to defend them; whilst some other parts may be much weaker, than the average nature of the ground in general.

In those parts, which are strong and inaccessible by nature, it may be sufficient to erect a simple parapet, with batteries on advantageous situations. Such, for instance, is a part of the land front of Gibraltar, which presents a rocky precipice, several hundred feet in height, not to be surmounted by an enemy.

In other parts, where the soil is marshy, inundations may be formed, and wet ditches or other water defences may be applied, with so much effect, as to render the expense of masonry superfluous. In other parts revetments may be absolutely necessary.

In some parts, the ground may be so very unsuitable for the construction of bastions and curtains, that redans, of an irregular form, must be used for the outline of the fortress: and it is to be remarked, that this circumstance will often be found to occur, in those parts of the inclosure, which are the strongest by nature.

In other parts, a simple bastionary outline, without ravelins, may suffice; whilst in other parts, ravelins or other outworks may be necessary.

In other parts again, by reason of the peculiar weakness of the ground, advanced or detached works may also be necessary, in order to create additional obstacles to an enemy's progress, and thereby put this defective portion of the inclosure, upon a par, in point of strength, with the remainder of it.

When ground is very irregular, a chain of detached forts, or casemated redouts, the nature of which was explained in a former chapter, may also be sometimes used with advantage, in lieu of a continued inclosure.

In short, a thousand varieties may occur in practice, for which it is difficult to lay down any precise rules beforehand: and therefore a very wide scope is left for the exertion of talent and judgement, on the part of an engineer, who is called upon to give in a project

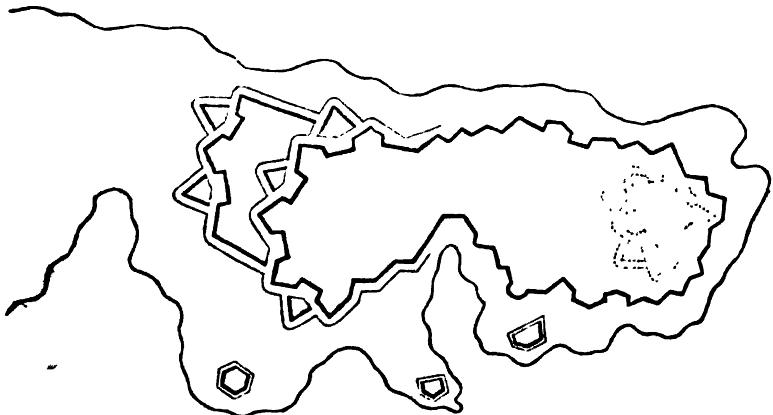
of permanent fortification, of any extent or importance: for so seldom can uniformity of ground be expected, that it scarcely ever happens, that more than three or four fronts of any fortress, which has actually been constructed, are to be found exactly alike.

It ought to be remarked, that the term "IRREGULAR FORTIFICATION," signifies merely the application of the art of fortification to irregular ground; which occasions an inequality in the dimensions of the corresponding parts of a fortress so constructed. It does not therefore imply any defect, either in the plan or execution of the various works. Consequently A PLACE IS SAID TO BE REGULARLY FORTIFIED, meaning that it is constructed according to the regular rules of the art, judiciously applied, notwithstanding that the outline of it may be very irregular: whilst on the other hand, the plan of a place may be quite regular, and yet it may be very badly or imperfectly fortified, by reason of the weakness of its general profile.

The only mode, in which irregular fortification can be learned to advantage, is to collect accurate plans and descriptions of a variety of fortresses, which have actually been constructed, and more especially of those which have been often besieged; for, as I before said, few or no fortresses are perfectly regular. Then by studying the history of their sieges, which will be done to most advantage upon the spot, if circumstances will permit; the advantages or defects of the various expedients, which have been adopted, at various times, for occupying irregular ground, by defensive works, may be understood. The same remark will therefore apply to this branch of our subject, which was before made, in alluding to the various systems of fortification, invented by a great number of engineers, or writers on that art, from time to time: namely, that it will be much best for a learner, not to enter deeply into the study of it, until he has previously made himself master of the most effectual means of attack, which have hitherto been used, in besieging fortified places.

Without enlarging further upon this subject, I shall therefore conclude by observing, that when ground is irregular, those parts of the general outline, which are susceptible of bastionary fronts, should first be drawn, in the form of an irregular polygon. This being done, upon each of the sides of this irregular polygon, as an exterior side, a front of fortification should next be drawn; and in the whole operation, the general rules and proportions, given in Chap. XVI, should be kept in view, as much as circumstances will permit; observing, however, that it may not, in all cases, be expedient, to make the two demibastions in the same front exactly alike.

As a specimen of the variations, which may take place in the outline of works of fortification, built upon irregular ground, the following sketch is added, to represent a fortress situated on a rocky peninsula, which we shall suppose to be inaccessible or nearly so, in all those parts towards the sea, which are occupied by a line of irregular redans.*



In a place situated on the sea coast, that part of the general line of works, which faces towards the water, is called THE SEA LINE

* The dotted pentagon represented in the figure, shows the position that might be chosen for a citadel, a kind of work, which will afterwards be explained.

OF THE FORTRESS; while the remaining part of it, which faces towards the country, is called THE LAND LINE, and the particular fronts of fortification, of which it is composed, are called THE LAND FRONTS. In like manner, in a place situated on the banks of a great river, there may be THE RIVER LINE, and THE RIVER FRONTS of the fortress, in opposition to the land fronts: and by way of distinguishing the principal gates of fortresses, so situated, those which face towards the water, and communicate with the wharfs frequented by boats or shipping, are called WATERPORT GATES, or sometimes simply waterports, whilst those which communicate with the country, are called LANDPORT GATES, or landports.

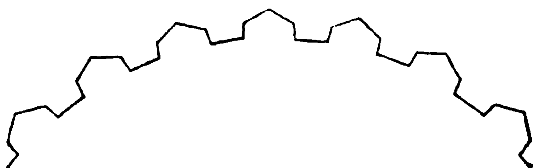
Having now explained the principles of irregular fortification, as far as is necessary for an elementary work, we shall next treat of citadels.

A citadel is a fort or smaller work, attached to a fortress of importance, sometimes as a keep or retreat for the garrison of the fortress, in case the principal works should be taken; and sometimes with a view to overawe the inhabitants of a disaffected city.

Citadels, if regular in their form, are usually made pentagons; the square, generally speaking, being considered too small a work to make a good defence.

Citadels have most commonly been constructed, so as to form a part of the exterior general line of defence, of the fortresses, to which they have been attached. In that case, there is a break in the body of the place, which is filled by the citadel.

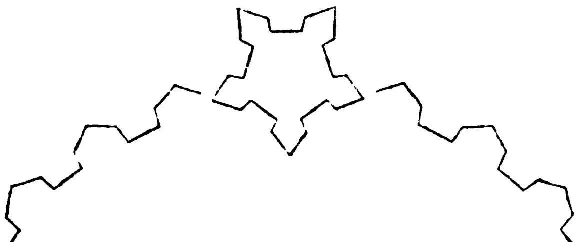
To exemplify this construction, you will first draw a figure with seven bastions, to



represent part of the main inclosure of a regular fortress.

Rub out your center bastion, and the inward flanks of the two COLLATERAL BASTIONS, that is to say, of those two bastions on each side, which are nearest to it: and rub out also the intermediate curtains.

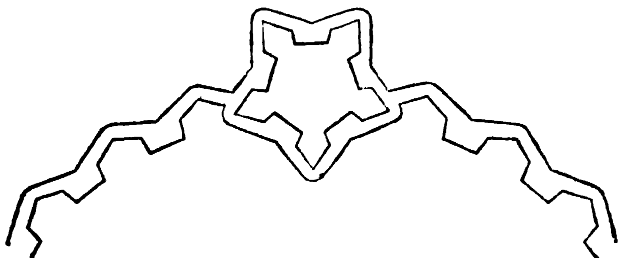
In the opening, thus left in the main inclosure of your supposed fortress, construct a regular pentagon.



The pentagon, which you have just drawn, represents a citadel attached to your supposed fortress, according to the system, which has been in most general use.

Both the citadel and the body of the place, shown in our figure, may have ravelins and other outworks attached to them. The citadel has also its covered way and glacis, not only towards the country, but likewise in those fronts of it, which face towards the interior of the fortress; and the ditches of the body of the place and citadel may communicate with each other.

You need not draw any ravelins, &c. as the proper manner of inserting them may easily be understood. Draw only the counterscarps of your figure to represent the manner, in which the various ditches may communicate, as above mentioned.



Sometimes, those parts of the main inclosure of the fortress, which terminate on the counterscarp of a citadel, have been laid out, not in the manner represented in our present figure, but in the form of long faces, enfiladed or flanked by the more projecting works of the citadel, and extending about 200 yards in a continued right line; and it has further been recommended, to give to the terrepleins and parapets of these long faces or branches, a less substantial profile than usual. These precautions, it may easily be conceived, are taken, in order to prevent the adjoining works of the fortress from being used to the prejudice of the citadel, in case the latter should hold out the longest, against a besieging army.

Long faces, constructed for the above purpose, on each side of a citadel, are called FACES OF COMMUNICATION.

In the interior of a fortress, which is constructed with a citadel, no houses or walls must on any account be allowed to be built near to the citadel; but an open or level space must be preserved all round, which must at least extend beyond the utmost range of musquet shot.

The open space, thus laid out, is called AN ESPLANADE; and the same word was formerly used to denote a glacis.

If an esplanade were not preserved in front of the citadel of a fortified place, an enemy who had got possession of the town, would fill the opposite buildings with soldiers, who by a close fire of musquetry, from windows and loopholes, might destroy the men on the ramparts of the citadel, without being seen by them, so as to render it impossible for them either to man their guns, or to make any adequate defence whatsoever.

It has been laid down as a rule, that the exterior fronts of a citadel should be made stronger, if possible, than those of the main inclosure of the fortress itself; for as the capture of the citadel will evidently open the way into the body of the place, if the

assailable fronts of the citadel were the weakest parts of the general line of defence, an enemy would attack them, in preference, as being the easiest mode of making himself master of the whole.

If, on the contrary, the assailable fronts of the citadel are much stronger than the rest of the line, the besiegers may be obliged to attack the fortress first; so that the citadel will serve as a keep for the garrison, and will place the enemy under the necessity of undertaking a second siege.

Citadels have, however, more often been constructed with a view to overawe the discontented population of a fortified city, than as keeps; and therefore, they have necessarily been placed upon the general exterior line of defence, in the manner represented in our present figure, so as to maintain an open communication with the country, in order that the garrison might thereby be enabled to receive succours from their army in the field, in case of an insurrection on the part of the townspeople. And for this reason, the principal gate of a citadel, facing towards the country, has often been called THE GATE OF SUCCOUR.

There is only one situation, in which a citadel can conveniently answer both purposes, that is to say, when it is constructed on or near the inaccessible extremity of a fortress, which, by reason of natural obstacles, cannot be attacked, with any prospect of success, on more sides than one. Thus, for example, in the first figure of this chapter, which was given to illustrate the nature of an irregular fortress, supposed to be inassailable towards the sea, it will be evident, that a citadel, placed in the position represented by the dotted lines, will serve the double purpose before mentioned; that is to say, it will not only overawe the inhabitants, but will also give the enemy the trouble of a second siege, since he has no means of approaching it until the exterior works are taken. At the same time, a citadel, so situated, although not to be relieved by land, might, in moderate weather,

conveniently receive succours of men and stores, from a friendly fleet.

Excepting in situations partially inaccessible, like the above, citadels cannot add materially to the resistance of a fortress against a regular army, at least by no means in a degree proportionate to the expense of building them. When, therefore, the only object in view is to keep in check a discontented population, this may sometimes be effected, in a more economical manner, by what is called countertrenching a few of the principal bastions of the main inclosure.

A COUNTERTRENCHMENT signifies an interior intrenchment, constructed in or behind any work, the parapets of which do not face outwards, or towards the country, like those of the original work, but are directed towards the rear.

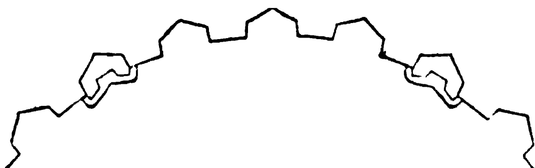
Countertrenchments do not, therefore, oppose any additional obstacles to a besieging army, in assaulting those particular bastions, behind which they are constructed. They are only useful, when the works, so strengthened, are attacked in rear, which in most cases supposes an internal enemy. If, however, in the course of a siege, any of the other bastions of the main inclosure should be breached, whilst the countertrenched ones are left untouched, then even the latter will be useful, in case of an assault, against the besiegers' troops, by preventing them from being able to extend themselves, and to gain easy possession of the ramparts on each side, after entering the place.

To exemplify this construction, rub out your citadel, and restore the outline of the fortress to its original state.

Then let two of your bastions be converted into keeps against an internal enemy, by drawing a countertrenchment in the rear of each, which may be laid out in the form of a small front of fortification.

Draw also ditches extending round your keeps, and let them be

continued on each side, so as to cut off the countertrenched bastions from the adjoining curtains.



There must be a proper communication between a countertrenched bastion, and the interior of the fortress, either by a bridge and drawbridge, or otherwise, in front of which there may also be a covered way with a place of arms; and when the ditches are dry, the scarps of the countertrenchments should be reveted.

CHAP. XXIII.

OF THE MODE OF FORTIFYING A MARITIME FRONTIER. OF COAST BATTERIES, AND MARTELLO TOWERS.—OF FIELD POWDER MAGAZINES, TIMBER BOMBPROOFS, AND ABBATIS.

We shall now treat of the proper mode of fortifying a maritime frontier.

The principal naval stations and dock-yards in every country, should be regularly fortified; and in addition to a common fortified inclosure, it may be expedient to secure them against bombardment, by a chain of detached works, as was before mentioned.

For the protection of harbours of secondary importance, forts, casemated redouts, or towers, commanding their entrances, may suffice.

To defend an open beach or landing place, against the disembarkation of an invading army, batteries, supported by towers, have been considered a good expedient.

When the nature of the beach is such, that vessels cannot approach nearer than to the distance of 300 yards, or thereabouts, from the spot, upon which defensive works are proposed to be constructed; common field batteries will be more than a match for shipping, as long as the contest is confined to a cannonade alone, even although the latter may be able to bring four or five times as many guns into action. The reason of the decided superiority, which a common battery thus possesses over a ship of war, of much greater force, will be readily understood from the following simple considerations. A field battery, properly constructed, is shot proof, and incombustible, and its guns may be laid with precision: whereas a ship may be set on fire; its sides are penetrable by shot; and unless in a perfect calm, its guns cannot be laid with sufficient precision. Moreover, the comparative size of the two contending objects is also a great disadvantage to a ship of war, in engaging a battery.

The guns, intended for the defence of a coast, should always be mounted on traversing platforms, which method affords a greater facility of firing quickly at ships under sail, in a variety of different directions. If on the contrary, the guns of coast batteries should be placed on common carriages behind embrasures, their scope of fire will be too limited to have sufficient effect; for vessels or gun boats may often be able to place themselves out of the line of most of the embrasures of a battery, so constructed, and yet in such a position as to annoy it by their own fire.

With respect to barbet batteries, they may, generally speaking, be pronounced entirely unsuitable for the defence of a coast; because, excepting when they are placed on high cliffs, or other situations of a very commanding nature, they afford scarcely any protection to men against the fire of shipping; and if used in semicircular bays, or other positions, where one defensive battery flanks another, the troops, posted in them, not being covered by

proper parapets, are liable to destroy each other by their mutual fire, in acting against a common enemy, particularly when grape shot is used.*

When the shore is low, and of such a nature, that ships can approach within close musquet shot of any spot, chosen for a defensive battery; it is then necessary, that the interior of the battery should be covered at top, by a proper musquet proof defence; otherwise marksmen, placed in the ships' tops, will be able to destroy the men in the battery, by a plunging fire. A casemated battery, open in rear, is therefore the best that can be used, in such situations, but it is not absolutely necessary that the arches should be bombproof. And it is to be observed, that in a woody country, a roof formed of stout beams of timber covered with about a foot of earth, and supported by posts or uprights at proper intervals, may be used to advantage for the same purpose, in lieu of arches and piers.

It will easily be understood that a field battery, although, in almost all cases, superior to a ship of war, in the effect of its

* In all works flanked by others, the same risk must occur, to a certain degree, if the parapets are low. But in a permanent fortress, the ditches, against which the fire of the flanking works would chiefly be directed, in case of an assault, are so much lower than the parapets, that no inconvenience is to be apprehended by the defenders of the flanked works. It has been remarked, that shot fired for the purpose of flanking any face of a bastion, ravelin, &c. are usually glanced off with considerable force, whenever they strike the circular part of the opposite counterscarp, in such a direction as to scour the ditch of the other face of the same work. Consequently, in the redan system, the shot fired from one flanking casemated battery are often, after being thus turned off, impelled towards some other casemated battery of the same work, and if by any accident they should enter the embrasures, they might be prejudicial to the defenders. But this is a rare contingency, so seldom likely to happen, that it may be disregarded; and if an enemy were actually engaged in an assault, the double fire thus produced by the bounding shot, would be of importance.

fire, can afford little or no defence against an enemy, when landed. But although arrangements are always made for manning the whole of the guns, placed in battery on a coast; the number of men, employed in this duty merely, are entirely inadequate to resist a landing of seamen and marines, even from a single ship: nor is it practicable for the most populous and wealthy nation, to have a force sufficient to oppose such enterprises of a hostile fleet, on every accessible point of its line of coast. It therefore becomes absolutely necessary, to support the field batteries, which may be constructed on various parts of a maritime frontier, by works of a more substantial and stronger nature, such as are not liable to be easily taken by a sudden assault.

Sometimes, with a view to the above object, earthen cavalier batteries have been made, with a ditch in front, secured by palisades, fraises, or other obstacles, and inclosed in rear, either by a loopholed brick wall, or by a defensible guardhouse or barrack; in such a manner, as to form a kind of redout.

A DEFENSIBLE GUARDHOUSE implies a building, capable of receiving either the whole or a considerable proportion of the men, who are necessary for the defence of any work, so as to serve the purpose of a keep, in case an enemy should penetrate into the interior of it; and for this reason, the walls, which ought to be built in a substantial manner, are always crenneled. The roof ought either to be arched over with a terrace at top, or at least it should be so constructed, as not to be liable to be easily destroyed by fire.

I shall here remark, that defensible guardhouses, such as have been described, may not only be used as a protection to sea batteries, but may also be employed to advantage, in inland positions, in the defence of redouts, or other works, not casemated; and in all cases, their walls, if possible, should be covered against cannon shot by the parapets of the work, within which they are constructed.

Casemated redouts for the defence of a coast have sometimes been made circular, but in most cases a different form would be preferable, for it is seldom to be supposed, either that they can be equally liable to attack on every side, or that they can be required to act against shipping, &c. with an equal number of guns in every direction.* In those sides of them, which face towards the sea, a

* The dimensions of a casemated circular redout, which has actually been constructed on the coast of England, are as follows.

Its exterior diameter is about 130 feet at top, with parapets from 10 to 11 feet thick, and terrepleins 34 feet 6 inches broad, so that there remains an open area, or interior space, of about 90 feet in diameter.

The exterior height of the scarp revetment is nearly 34 feet at the merlons, but 32 feet only at the embrasures. The terreplein is fitted up for 10 heavy guns, mounted on traversing platforms, which fire through the shallow embrasures, above noticed, the interior height of the parapet at the merlons being 8 feet. There is a banquette 3 feet wide throughout, and 2 feet high in front of the guns, but 3 feet 6 inches high in other parts. There are disengaged traverses between the guns, 8 feet wide, 15 feet long, and 3 feet distant in front from the parapet. There is a gateway 10 feet wide, with a bridge and drawbridge for entering the redout. The communications, between the terreplein and interior area, are by three staircases, each 4 feet wide.

The redout is covered by a glacis, having a slope of $7\frac{1}{2}$ to 1, the line of which produced cuts the scarp, about 2 feet 6 inches below the soles of the embrasures. The counterscarp revetment is about 20 feet high, and 5 feet 3 inches thick at bottom, with a moderate slope. The ditch is about 28 feet 6 inches wide at top, and has a dip at bottom of 5 feet, being deepest on the scarp side.

The scarp revetment is 3 feet 6 inches thick only, in front of the casemates, but the lower part of it, which is faced with granite, is increased to the thickness of 13 feet at bottom, being laid out with a very great slope. The casemates are 35 in number, of which seventeen are rectangular, the remainder being of an irregular width. The former are alternately 15 feet $7\frac{1}{2}$ inches, and 11 feet $7\frac{1}{2}$ inches wide. The piers are each 3 feet thick, and 7 feet high, measuring from the wooden floor to the spring of the arch, and are intersected by doors of communication, 4 feet wide. All the casemates have a circular loophole in front, of 1 foot exterior diameter, and airholes, 9 inches square, finishing below the banquette. The irregular

double tier of guns may be mounted, if thought proper, part on the terreplein of the redout, the remainder in casemates below. This of course implies that there is either no counterscarp, or a very low one, in that direction.* On the land side, where a counterscarp is absolutely necessary, if the work is intended to make a good defence, a double fire of this nature cannot properly be obtained.

Towers, armed with cannon at top, have always been considered a good expedient for the defence of a coast, and have been built of various shapes and sizes, in different countries and situations. Of late, however, round towers, mounting from one to three, and not exceeding four guns, upon traversing platforms, have, upon the whole, been deemed the best adapted for the protection of an open beach; and have accordingly been constructed, in great numbers, in the British dominions, both at home and abroad, particularly in the most accessible parts of the southern and eastern coasts of England.

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casemates have only one airhole, the others two. Each casemate has one fire place, excepting those fitted up for officers' quarters and cooking places, which have two. They are each inclosed in rear by a wall 2 feet 3 inches thick, with a door and two windows, and a circular aperture over the door. The rise of the arches of the casemates is 7 feet 9 inches, the total depth of masonry over the crown of each being 4 feet 6 inches. The terrepleins are 6 feet 6 inches high, in front, above the crown of the arches, and have a reverse slope of 1 foot towards the central area. Almost the whole of the redout above the level of the floor of the casemates, is built of brick: below that level, granite, as before mentioned, and rough stone are used.

* In projects which I have seen for fortifying their coast, the French are very fond of multiplying artillery to a superfluous degree, proposing often to use two or even three tiers of heavy guns in their casemated sea batteries, when one ought to suffice. It is however to be observed, that in building a casemated coast redout, it may generally be advisable to have casemated embrasures in all those sides of the work which face towards the sea, for as the casemates themselves must necessarily be constructed for the accommodation of the garrison, whether they are ever likely to be required as batteries or not, there can be no disadvantage, rather the contrary, in preparing them for this extra service, in case of emergency.

Towers of this description have lately been distinguished by the title of martello towers, in consequence of a good defence made by a small round tower of that name, in the island of Corsica.

Martello towers should be at least 30 feet in exterior height, in order that they may not be easily carried by escalade; and their walls may have a small exterior slope, not exceeding one twelfth of the height. Their exterior diameter will of course depend upon the number of guns, proposed to be mounted. The smallest of them have been about 30 feet high and 35 feet exterior diameter at top; the largest have been about 35 feet in exterior height, and seldom exceeding 50 feet in mean diameter at the top, measured also exteriorly. The term "mean" is used, because the larger kinds of martello towers have seldom or never been made exactly circular, as shall hereafter be explained.

Martello towers are built with two stories, of which the upper one serves for the accommodation of the troops, and is covered by a bombproof arch or arches. The lower story should also be covered by light arches; or at least by a floor of incombustible materials: and it is usually divided into three or four small apartments, one of which serves for a powder magazine, the others being appropriated for provisions and other stores. A small cistern or tank is also usually placed, somewhere in or below the lower story. Above the bombproof arch there is a flat terrace, formed entirely of solid masonry, upon which the gun or guns are mounted, and which is secured all round by a parapet and banquette. The total depth of masonry over the crown of the arch is seldom less than 5 feet; the usual height of the parapet being about 6 feet; and the width of the banquette 1 foot 6 inches.

The entrance of a martello tower is by a door, placed nearly on the level of the floor of the upper story, to which the communication from without is either by a ladder or by a drawbridge. The upper story communicates with the lower one, by a trapdoor or hatchway and ladder, or sometimes by a staircase, and with the terrace at top

either by a shaft, cut over the doorway, and a ladder, or by a spiral staircase, or by one or two common staircases. There are always loopholes serving as windows, in the upper story, but there are seldom any external apertures in the lower story, which is ventilated by winding air-holes, usually carried up towards the top of the tower. There is a fire-place and chimney in the upper story, and some towers have had a small furnace for heating shot. The doors are placed towards the land, that being supposed to be the most secure side ; for which reason the mean thickness of the walls has usually been made rather less on that side, than towards the sea. By reason of this difference, these towers have sometimes been built of an elliptic form exteriorly, whilst the interior of them has been made circular.

Towers and casemated coast redouts are built entirely of masonry in every part : for by reason of the superiority, above-mentioned, which guns on shore generally possess over shipping; walls and parapets, constructed with brick or stone, although not calculated to resist land batteries for any length of time, will remain good, until the vessels engaged with them are completely disabled. Hard stone should, however, not be used in parapets of any kind, if brick or soft stone are to be procured; the former material being much more liable to produce dangerous splinters.*

The walls and parapets of towers and casemated redouts, intended for coast defence, are seldom made more than 12 or 13 feet thick, on their most exposed sides; nor are their parapets ever made less than 6 feet thick, in their weakest parts. When their walls are covered by a counterscarp and glacis, which is sometimes done, the thickness of the masonry may of course be greatly reduced, care being taken, however, that there shall be sufficient strength left

* For this reason, loopholed walls, serving as keeps or retrenchments, are never built of hard stone.

in all those parts, which may serve as piers or abutments to the bombproof arches.*

In the small martello towers, the bombproof arch has often consisted of A DOME; which signifies an arch, springing from one continued circular pier, formed by the exterior walls of the tower, so as to resemble a hollow hemisphere or half globe. Sections taken through the center of this kind of arch, in every possible direction, are all exactly alike. In the larger towers, annular arches have often been used; that is to say, arches springing from two concentric circular piers, one of which is formed by the exterior walls of the tower, whilst the other consists of a small round pillar, built in the middle of it. In any section taken through the center of a tower, constructed in this last mentioned manner, two arches will appear; but in reality they are to be considered as only one continued arch, the plan of which is circular, so that it incloses a space like a ring; from which circumstance it derives its name. The central section of a dome, as also the perpendicular section across any part of AN ANNULAR ARCH, may either be a semicircle, ellipse, parabola, or segment of a circle, or

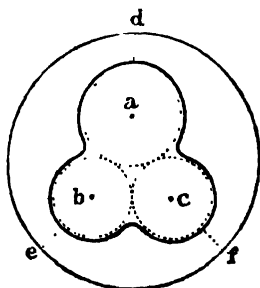
* In parapets built of masonry, about one foot of the top of the parapet, near the interior crest of it, is usually laid out horizontally, or nearly so, beyond which the regular superior slope commences. When embrasures are cut in such parapets, it is also to be observed, that the neck or narrowest part of the embrasure does not exactly agree with the interior slope, as in a field battery, but is commonly placed about one foot more to the front, beyond which the usual splay commences. Those small portions of each cheek of an embrasure so constructed, which are in rear of the neck of it, have also a splay backwards, proportional to the exterior splay. Consequently the outline of each cheek of a masonry embrasure is represented in a plan, by two lines of very unequal lengths forming an obtuse angle, each short line of the one cheek, being nearly parallel to the long line of the other.

In military works, the general mass of which is built of brick, all angles, copings, &c. are generally faced with soft stone, when it is to be procured, and large blocks of hard stone are preferred for the foundation.

in short of any form, used in the other more common kinds of arches, which spring from parallel right-lined piers.

Sometimes instead of domes or annular arches, common arches have been used for martello towers. This method saves trouble in the workmanship, but it gives the arch a very irregular appearance, because the interior of the tower is either laid out in a circular form, or in the shape of a polygon, so as to approximate, in some degree, to the general outline of the exterior curve; and it must be evident, that unless the space covered by a common arch is rectangular, the arch cannot possibly have an uniform span and rise, throughout every part of its extent.

A long gun, mounted on a traversing platform, requires an interior space of about 20 feet diameter, within the parapet, to be able to traverse freely in all directions; and a carronade or lighter gun requires 16 feet. If therefore three dotted circles touching each other are drawn, one from the center, a, with a radius of 10 feet, the others from the centers, b, and c, with a radius of 8 feet each, the areas of all these circles added together will point out nearly the whole interior space, which ought to be comprehended within the parapet of a martello tower, capable of mounting one long and two lighter guns. Afterwards by drawing an exterior circle through three points, d e f, chosen in such a manner, that there shall not be less than a certain number of feet, 6 for example, comprehended between them and any part of the circumference of the smaller circles, this will give the general extent of the exterior diameter at top of the required tower; as is represented in the following figure. The thick curved line, immediately inclosing the dotted circles, shows the form, which it is proper to give to the interior crest of the parapet, of a tower constructed for mounting more guns than one; it being desirable, that the muzzles of the guns should always project beyond the interior



crest of the parapet, which would not be the case, unless the latter were curved in such a manner, as to agree nearly with a considerable portion of each of the arcs, described by the several traversing platforms in their motion.*

It will be obvious, that whenever, for the above reason, the interior crest of the parapet of a tower is indented or composed of a mixed curve, partly convex and partly concave, as represented in our present figure; the exterior crest of the parapet, and consequently the exterior outline of the tower, need not be exactly circular, but

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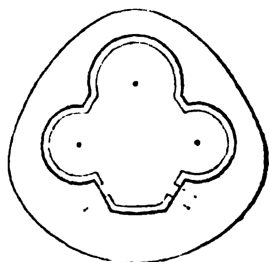
* If a line of heavy guns mounted on traversing platforms were never likely to fire except in the same direction, intervals of 12 feet would be quite sufficient. But as one gun may be required to be pointed in one direction, and the adjoining gun in a contrary one, at the same time, their two traversing platforms would interfere with each other, if less than about 20 feet were allowed, as stated in the text.

The regulation traversing platform for heavy guns consists of two strong side pieces, which are 16 feet long, and cover a space of about 5 feet 2½ inches wide, from out to out. They are connected by three transoms or cross pieces. The center of the fore transom is 1 foot 6 inches, that of the middle transom is 6 feet 3 inches, and that of the hind transom is 11 feet, from the front of the platform. Any one of these three points may be chosen for the pivot or center of motion of a platform of this description, which consequently may either be made to traverse in front, in center, or in rear. The four trucks, upon which the platform moves, are fixed under the side pieces, near the extremities of the fore and hind transoms, and their axles must be directed towards the center of motion. They move either upon hard stone, or on narrow iron plates of a circular form, fixed down upon wood or stone. These plates are called THE KIRBS, OR sometimes THE RACERS OF A TRAVERSING PLATFORM.

When guns, mounted on traversing platforms, are placed in rear of any right-lined face of a work, it is best to use platforms traversing in front. A traversing platform having its pivot in center has been recommended for acute salient angles, and the pivot in rear has been recommended for more obtuse salient angles. The two last kinds of traversing platforms are the best adapted for towers. It is to be remarked, however, that peculiar traversing platforms have often been made on purpose for particular towers or other works, differing in their general dimensions and construction, from those which have been mentioned.

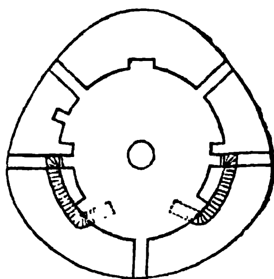
may be made in the form of some irregular or mixed curve, so as to approximate to the interior outline of the parapet to a certain degree. This has been attended to in planning some of the large towers on the coast of England, which mount three guns.

The annexed figure shows the plan of the top of one of these towers, in which the interior and exterior crest of the parapet, and the banquette are represented, as also the pivots of the three traversing platforms, from which points, as centers, the circular portions of the interior of the parapet are described. The least thickness given to the parapet in any part is 6 feet. The exterior curve is an irregular figure, composed of seven circular arcs, described from so many different centers, its two greatest diameters at top being 50 feet 7 inches by 47 feet 7 inches, which dimensions are increased, towards the bottom of the tower, by an exterior slope of one twelfth. The dotted lines show the position of the heads of two staircases, for ascending upon the terrace.



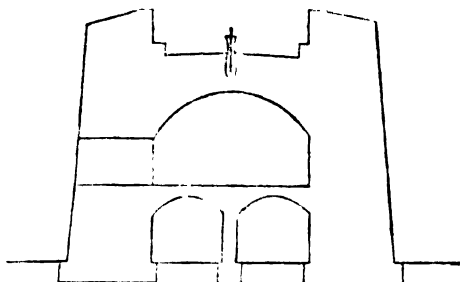
As a further illustration of the nature of these towers, a second figure is added, representing the plan of their upper story.

In this, the principal door of the tower, as also four windows, and two fire-places, and the two staircases, before mentioned, are distinctly shown. The small interior circle represents the central pier of the annular arch. Partitions, inclosing a small apartment for an officer, between which and the said pier a narrow passage is left, are omitted for the sake of clearness.



In the following figure, the section of one of the smaller martello towers is given, which, being supposed to mount one heavy gun only, may be about 20 feet interior diameter at top, measuring from

the interior crest of the parapet on one side to the corresponding point on the other. The upper arch, which in section is a circular segment, may represent a dome. The two arches of the lower story, may either represent an annular arch, winding round a central pier, or what for a small tower would be more convenient, they may represent the central section of two common segment arches, which, for the reason before mentioned, would, in other parts, towards their extremities, be of an irregular form. The pivot of the traversing platform is represented above the principal arch, consisting of an iron nine-pounder gun, properly fitted up and built into the masonry; this being the expedient most usually adopted for that purpose.



It ought to be clearly understood, that the chief advantage of martello towers is their non-liability to be instantaneously entered and taken possession of, by sudden assault, after the landing of an enemy: because as far as regards the mere effect of the guns mounted upon them, if engaged with shipping in a distant cannonade, there can be no doubt, but that the same number of guns would be equally efficacious, if placed in a common low field battery.* The round figure of the martello tower is some

* The name of Martello tower was adopted, as before mentioned, in consequence of the good defence, made by a small round tower in the bay of Martello, in Corsica, in the year 1794, which, although armed with one heavy gun only, beat off one or two British ships of war, without sustaining any material injury from their fire. But this circumstance ought merely to have proved the superiority, which guns on shore, must always, in certain situations, possess over those of shipping, no matter whether the former are

advantage, because when exposed to a cannonade, all the shot, which strike it obliquely, glance off, without materially injuring the masonry. This advantage, however, is of importance only against ships, whose fire is uncertain. In opposing a land battery, constructed within a moderate distance, and firing with the usual precision, it would be of very little avail, because almost every shot might be made to strike perpendicularly upon the center of the building. Martello towers are therefore not to be recommended in inland fortresses or positions; although no other kind of

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mounted on a tower or not. That this is a just decision, will perhaps be readily allowed, by all who are acquainted with the following equally remarkable but less generally known fact, which occurred about twelve years afterwards, in the same part of the world. A common two-gun barbet battery, situated on a commanding cliff on the coast of the kingdom of Naples, beat off a British 74-gun ship, supported by a frigate, occasioning a very severe loss to the former, although in the battery itself only one man was wounded. After the attempt to silence the battery by cannonade was found to be entirely hopeless, a party of seamen and marines were landed with a couple of field pieces, who in a very short time made themselves masters not merely of this insignificant work, which was quite open and defenceless, but of a substantial building in rear of it, serving as a keep, in which the enemy had taken refuge, with a view to defend themselves by musquetry.

The Corsican tower, before mentioned, which had in like manner completely baffled a naval cannonade, was very soon found to surrender, when attacked by land; not, however, before a small battery had been made to reduce it.

From what has been said in this chapter, it may be inferred that it is very imprudent for a ship of war to engage in a protracted cannonade with a properly constructed coast battery, unless in cases of extreme emergency, when the good of the service absolutely requires that a certain risk should be incurred. The vessels best adapted to contend with batteries, although even they will fight at a disadvantage, are small gun boats, mounting one long heavy gun in the bow, which ought always to spread themselves at considerable intervals apart, in order to prevent the battery fron concentrating its fire. Gun boats of this description are only efficient in a calm, when they can fire with great precision.

works are, upon the whole, better adapted for the defence of an open beach, against a hostile fleet.*

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* In order to give a more precise notion of the nature of some martello towers, which have actually been constructed within the last fifteen years, the following descriptions are added.

1st. The large circular towers, built in Minorca, when that island was last in possession of the English, were 55 feet in exterior diameter at top, their exterior height being 36 feet with a slope of 1-12th. The thickness of the parapet was 12 feet all round; its height 6 feet; its dip 2 feet 6 inches. The height of the lower story of these towers was 11 feet; over which was a wooden floor covered with paving tiles, total depth 1 foot 6 inches: the height of the upper story measuring to the crown of the arch was 15 feet 6 inches. The bombproof arch was a dome of a section nearly elliptical, the span of which was 31 feet, and its rise 11 feet 8 inches. The dome and exterior outline of the tower were described from the same common center. The thickness of masonry over the crown of the dome was 5 feet.

Above the principal entrance, which, like that of all the other towers about to be described, was a door placed on the level of the upper apartment, there was a machicooly, and a square hole or shaft for the conveniency of hauling up stores. The ascent to the terrace was by a spiral or winding staircase, cut in the wall. A hatchway and ladder led to the lower story, which was partitioned off into three apartments. There was a cistern excavated below the general level.

The towers which have just been described were very handsome, being faced with cut stone, both inside and out: and having a cordon and coping, the former at the height of 31 feet, above which the remainder of the exterior wall was built perpendicularly.

A long heavy gun, whose center of motion was in rear, was mounted on these towers; but as there was much more than sufficient room for one gun, a howitzer or carronade was also added.

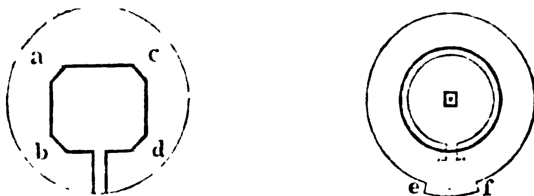
2d. The smaller circular towers, built in the same island, were 35 feet exterior diameter at top, their exterior height being 30 feet, with a slope of 1-12th or 1-15th. The thickness of the parapet was 7 feet 6 inches all round; its height 5 feet 10 inches; and its dip 2 feet 9 inches.

The form of the interior of the tower was an irregular octagon, which was described by first drawing a rectangle of 18 by 20 feet; and then setting off, from each angle, 3 feet upon the short sides, and 3 feet 3 inches upon the long sides. The adjoining points, thus found, being connected by right lines, formed the short sides of the required octagon, the center of which

It was before stated, that strong timbers may be used in lieu of arches, for covering a battery against a plunging fire. I shall

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did not correspond with the center of the tower, but was placed 2 feet 6 inches in rear of it towards the land side, in order to increase the strength of the masonry towards the sea. The plan of the upper story of one of these towers is represented by the first of the annexed figures, in which the original rectangle is marked by the letters, a, b, c, d. The second figure represents the plan of the top of the tower, in which the parapet and banquette and pivot of the gun are distinctly shown.



The height of the lower story of these towers was 9 feet up to the crown of the arches, by which it was covered: the thickness of masonry over which was 1 foot. The height of the upper story up to the crown of the bombproof arch was 10 feet. The two arches of the lower story were each 9 feet 6 inches span and 2 feet 3 inches rise, resting partly on the sides, a b, and c d, as abutments, and partly on an intermediate pier wall 1 foot thick. The bombproof arch rested on the sides, a c, and b d, as piers, and was 18 feet wide, with a rise of 6 feet. The depth of masonry over the crown of this arch was 5 feet 6 inches. The whole of the above arches were irregular in their appearance, being of course imperfect near the angular parts, a, b, c, and d. One of the arched apartments of the lower story was subdivided into two, by a partition wall. The exterior entrance or door of the tower was 2 feet 6 inches higher than the upper story, to which there was a descent of 4 steps. Over the door was a rectangular shaft about 2 feet 6 inches by 2 feet 10 inches, by means of which there was an ascent to a small machicooly chamber, represented by the dotted lines in the second figure, the interior width of which varies from 4 feet 6 inches to 6 feet 6 inches, in the clear. The machicooly was supported by 4 corbels, and projected 2 feet beyond the rest of the parapet, as is shown in the same figure. From the chamber to the terrace, there was an ascent of 3 steps each 1 foot high. The descent to the lower story was by a hatchway. Recesses not shown in the figure, were cut in the parapet of each of these small towers, for placing a grate to heat shot: in one of these towers, only, a small brick

conclude this chapter, by describing some other defensive purposes, that have not yet been noticed, to which woodwork may be applied, particularly in those countries in which trees are plentiful.

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furnace, for that purpose, was built in the said recess. As far as regards the general form of the interior of the above towers, and the nature of their arches, the construction used may perhaps be allowed to be one of the simplest and most convenient, that could have been adopted, provided that the principal entrance and shaft had not been pierced in one of the abutments of the great arch.

The whole of the towers, constructed in Minorca, had not only airholes for the powder magazine, but also a few loopholes or small windows cut in the lower story, besides several in the upper story. They were all founded on rock, having cisterns arched at top, cut out of the rock. In some of them, a small well-hole was sunk from one of the windows of the upper story, for drawing water from the cistern, without going down below.

One tower, built in the same island, was of a very peculiar construction, having a narrow circular crenneled gallery in the lower story, inclosing the powder magazine. The loop-holes of this gallery, which were pierced through the exterior walls of the tower, were not cut perpendicularly, in the usual manner, but obliquely, and either proceeding in angles from some common junction, or intersecting each other, in the form of the letters V and X. I thought it proper to mention this circumstance here, principally for the sake of defining these DIVERGING AND INTERSECTING LOOP-HOLES, as they are called, which are often to be met with in crenneled defensive works, particularly if the walls are thick. The same tower had also a counterscarp and glacis, and a crenneled counterscarp gallery of small extent, for the purpose of producing a reverse fire in the direction of the principal entrance.

In the remaining towers, which are about to be described, and which were built in various parts of the British dominions, there were no external apertures whatever, excepting in the upper story, the lower apartments being ventilated entirely by winding air-holes, about 1 foot square, carried up in the walls to a much higher level.

3d. Some towers were built of an ellipse like form exteriorly, their transverse and conjugate axes being 39 feet 6 inches by 36 feet 6 inches at top. The curve was composed of four circular arcs, described from so many different centers. The exterior height was 34 feet with a slope of 1-10th. The terrace was a circle of 24 feet diameter, the greatest thickness of the parapet being 9 feet 6 inches; its least thickness 6 feet; its height 5 feet 10 inches; and its dip 1 foot 9 inches.

In field works, such as redouts, &c. the powder magazines are always constructed of woodwork. The interior section given to

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The form of the interior of the tower is similar to that of the terrace, and immediately below it, being also a circle of 24 feet diameter. The lower story is covered by two common segment arches, the greatest span of which is 10 feet 10½ inches, their greatest rise being 3 feet 9 inches. They spring partly from a right-lined central pier, 2 feet 3 inches thick, and partly from the exterior walls as abutments, which, as these are of course nearly semicircular, occasions the said arches to be of a very irregular appearance, their section in no two parts being exactly alike. The upper story of the tower is covered by a segment dome of 24 feet span, and 6 feet 9 inches rise. The height of the lower story, measuring from the wooden floor to the crown of the arches, by which it is covered, is 8 feet 9 inches: the thickness of masonry at the crown of these arches is 1 foot 6 inches: height from thence to the crown of the dome, including the wooden floor of the upper story, 12 feet 2 inches. Depth of masonry over the crown of the dome 3 feet 6 inches.

Two staircases each 2 feet 6 inches wide, constructed in the thickest sides of the tower, lead from the upper story, one of them to the terrace, the other to the lower apartments. Their outline is parallel to the interior circle of the tower, from which they are divided by a wall 1 foot 2 inches thick, the inside of which corresponds with the said circle.

Below the wooden floor of the lower story is a tank 5 feet 1 inch high, measuring to the crown of a nine-inch arch, by which it is covered, the section of which is a segment of 10 feet span and 1 foot 2 inches rise. The thickness of the floor of the tank is 9 inches.

4th. Other towers were constructed, also of an elliptical form, exteriorly, their transverse and conjugate axes at top being 39 feet 10 inches by 36 feet 10 inches. Their exterior height was 32 feet, with a slope of 1-10th. The terrace was a circle of 26 feet diameter; the greatest thickness of the parapet being 8 feet 10 inches; its least thickness 5 feet; its height 5 feet 10 inches; and its dip 1 foot 2 inches.

The height of the lower story of the tower, from the level of the wooden floor to the bottom of the joists of the floor above it, is 7 feet 8 inches. The total depth of wood work of the floor of the upper story is 1 foot. The height of that story is 10 feet 7½ inches, measuring to the crown of the annular bombproof arch, which is a segment of 11 feet span, and 3 feet 2 inches rise. The total depth of masonry over the crown of the arch is 5 feet 6 inches. The central pier is 4 feet in diameter, which in the lower story is increased by offsets to 5 feet. The general outline of the interior

them, in field batteries in a siege, is usually a right-angled triangle, of which the base and height are nearly equal. The roof, which

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of the tower is formed by a circle of 26 feet diameter (including the above pier), the center of which circle is immediately below that of the terrace. About one fourth of the lower story is partitioned off by brick walls, and covered by light arches, which space is appropriated to the powder magazine and its vestibule, the body of the magazine being partly formed by a recess cut in the exterior wall of the tower, the thickness of which is thereby reduced to 7 feet 6 inches at that part. The descent to the lower apartments is by a hatchway: the ascent to the terrace is by a staircase 1 foot $10\frac{1}{2}$ inches wide, the interior wall of which is 3 feet thick, and projects 2 feet inwards, beyond the general outline of the upper story.

5th. The largest kind of tower, before-mentioned in the text, shall lastly be described more in detail.

The exterior outline at top is an irregular curve, (represented in the figure given in page 179) the transverse and conjugate diameters of which are 50 feet 7 inches by 47 feet 7 inches, as was before stated. The exterior height is 35 feet, with a slope of 1-12th. The circular portions of the terrace are described, one with a radius of 10 feet, the two others with radii of 8 feet each, the least thickness of the parapet, which is very irregular in its form, being 6 feet: its interior height 6 feet, and its dip 1 foot 6 inches.

The height of the lower story of the tower, from the level of the wooden floor, to the bottom of the joists of the floor above it, is 8 feet $9\frac{1}{2}$ inches. The total depth of woodwork of the floor of the upper story is 1 foot. The height of that story is 11 feet $9\frac{1}{2}$ inches, measuring to the crown of the annular bombproof arch, which is a segment of 14 feet 6 inches span, and 4 feet 3 inches rise. The total depth of masonry over the crown of the arch is 5 feet 6 inches. The central pier is 6 feet in diameter, which in the lower story, is increased by offsets to 7 feet. The general outline of the interior of the tower, is formed by a circle of 35 feet diameter (including the above pier) in the upper story, but by a circle of 34 feet only, in the lower story, the latter being reduced in width in order to obtain offsets for supporting the wall-plate of the wooden floor above it; a purpose which, in the last described tower, was effected by stone corbels. About one fourth of the lower story is partitioned off by brick walls, and is covered over by nine-inch arches, which space is appropriated to the vestibule and light room of the powder magazine, the body of it being partly formed by a recess of 14 feet by 4 feet 9 inches, cut into the exterior wall of the tower. The remainder of the lower story is partitioned off into various

corresponds with the hypothenuse of the triangle, and which consequently slopes on one side only, is formed of strong timbers of

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store rooms, and there are 4 recesses cut into the exterior walls in certain parts of that story.

In some of the towers, which we are now describing, the counterscarp is 22 feet high above the level of the ditch, of which 20 feet 9 inches are reveted, the remainder being formed with an earthen slope. The counterscarp revetment is 1 foot $10\frac{1}{2}$ inches thick at top, with a slope of 1-6th, its outline being perfectly circular, and described with such a radius, that the narrowest parts of the ditch are 35 feet wide at bottom. It has counterforts 1 foot long and 3 feet wide, built at intervals of 18 feet apart from center to center. The slope of the glacis is not quite regular, but in general, when produced, it cuts the tower about 2 feet below the exterior crest of the parapet.

The exterior walls of this and the last described tower had each foundations, about 5 feet deep, below the surface of the ground. Under the wooden floor of the lower story were inverted annular segment arches 1 foot 6 inches thick, the form of which as represented in a section is not regular, the center, from whence the curve is described, being much nearer to the exterior walls than to the central pier. The whole space below these inverted arches is filled with masonry, extending to the same depth as the bottom of the exterior walls, and connected with it, so as to form a continued solid stone foundation under the whole tower, the least thickness of which, at the parts immediately below the crown of the inverted arches, is 2 feet in the small towers, and 2 feet 6 inches in the larger ones.

In those towers, which had annular arches, the joists, that supported the floors, were generally laid diverging from the central pier like radii, and they were forked near their outward extremities, a shorter joist being bolted to each of them, in order to reduce the intervals there, which otherwise would have been too great. This method of flooring being troublesome in execution, joists laid parallel to each other, according to the common method, and partly supported by an intermediate pier wall, corresponding with the diameter of the interior circle, might be used in such towers to equal advantage.

All the towers, which have been described, had reservoirs, some under the floor of the lower story, others in leaden tanks placed in one of the store rooms. Their terraces had a proper slope with gutters and pipes to convey the rain water down into the tanks, which were provided also with waste pipes to throw out superfluous water, when sufficiently full. The tanks were not intended to be used on common occasions, for which reason wells were cut near the towers, particularly in the ditches of those which

from 8 inches to 1 foot square, with one end resting on the ground, whilst the other leans against the upper part of the interior revetment of the parapet of the magazine, which being composed of

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had counterscarps. In addition to a principal tank containing about 800 gallons, there was a smaller tank, in each of the large towers, capable of containing about 450 gallons; which was allowed for daily use, and was replenished when necessary from the well outside. In these towers there was a pump in the upper story, and other conveniences for drawing water from the well, and either discharging it into the expense tank, or raising it from thence.

The whole of the towers had banquettes, of hard stone, about 1 foot 6 inches wide, and from 1 foot 6 inches to 1 foot 9 inches high. The fore trucks of the traversing platforms of the lighter pieces of ordnance, when such were used, commonly rested on these banquettes.

In some of the second rate towers, in addition to one long heavy gun, mounted on a common traversing platform, the pivot of which was fixed in the center of the terrace, one or sometimes even two carronades, or howitzers, were fitted up with traversing platforms of a peculiar construction, so contrived, that these and the former traversed by means of the same pivot, and yet could fire in the same direction nearly. This system was not however found convenient, for when guns are so mounted, the recoil of one is always liable to impede the manœuvres of another. It has therefore since been laid down as a rule, that whenever more pieces of ordnance than one are used, each of them should have its own distinct pivot, with sufficient room to traverse independent of the others.

The doors of the towers seldom exceeded 6 feet 6 inches in their greatest height, or 3 feet 6 inches in their greatest width, some of them being much smaller. In case of attack, it was intended, that they, and a part of the whole of the windows, should be blocked up with sandbags, which therefore formed an article of store, earth being also provided for filling them, when required. With a view to this emergency, in the three last described kind of towers, numerous air-holes were cut, not only in the lower, but also in the upper story.

It will easily be conceived, that although the general and most important dimensions of martello towers may be fixed by brief descriptions, such as those which I have just given, there are many lesser details not to be understood, without more ample explanations, illustrated either by a number of appropriate drawings, or by a model. I shall conclude by observing, that guns may not only be mounted on the terrace, but also behind casemated embrasures in the upper story of towers, if it were judged necessary, and this practice has in some few cases been actually adopted.

earth of proper height and thickness, covers it against direct shot from the enemy's guns. By this construction, as the above beams are laid nearly at the same angle of inclination, at which an enemy's shells must necessarily descend in falling, any shell that strikes the roof of the magazine, will glance off without penetrating into the body of it. But in field redouts, if this construction were followed, in building the necessary powder magazines, they could not always conveniently be made spacious enough to contain the whole quantity of gunpowder required; and therefore they are sometimes formed with a double set of beams, sloping on both sides, and meeting in a ridge at top, like the roof of a common dwelling house.

When this last described method of constructing a field powder magazine is followed, it will be evident, that shells cannot possibly be glanced off by both sides of the ridge. In falling upon one of the sides, they may strike the beams perpendicularly, or nearly so. None, therefore, but very strong sound timbers should be used in this case, which should be connected by proper braces, and otherwise put together in a substantial manner; and they should afterwards be covered by several feet of earth, without which they cannot by any means be considered secure. In order that field powder magazines may not be too conspicuous, they are, in dry soil, always sunk some feet below the surface of the ground, and the rain water is prevented from entering them, either by a cesspool, occasionally baled out, which is sufficient in a common open battery; or by a drain, communicating from the magazine to the ditch of the work. This drain, in a redout or inclosed work, usually passes under the gate or entrance.

A very extensive use of woodwork, even in permanent fortification, has been recommended by some authors, who propose that bombproof casemates, and crenneled counterscarp galleries, should be formed thereof. If this suggestion were followed in practice,

the roofs of the said casemates and galleries may be composed of strong beams laid horizontally or nearly so, properly supported by uprights at certain intervals; and the greater the depth, that can conveniently be given to the woodwork of the roof, as well as to the superincumbent mass of covering earth, so much the stronger will these TIMBER BOMBPROOFS be. It is to be remarked, however, that this construction can only with propriety be recommended for immediate use, in fortifying a well wooded country under critical circumstances; for as casemates and galleries must necessarily be covered with earth, the woodwork will decay, in a much shorter time than that of a common building: so that, upon the whole, masonry is preferable, as being eventually a cheaper material.

In fortresses not provided with proper casemates, temporary bombproofs are often hastily constructed in case of a siege, by choosing some part of the revetments, which are not exposed to the effect of the enemy's batteries, and setting up strong timbers against them at an angle of about 45°. Thus are formed a kind of sheds or huts for the reception of the men, who are not on duty; the section of which is triangular, and which are usually called SPLINTERPROOF ACCOMMODATIONS, because they are more likely, by reason of their slope, to be struck by the fragments of a shell after it bursts, than by the shell itself in falling.

A BLOCKHOUSE signifies a defensible barrack, formed of woodwork, which is generally armed with guns on its upper story, being always made at least two stories high. The walls are built of strong timbers not less than 1 foot thick. The upper story should project about 3 feet, the whole of which projecting part should have vertical loop-holes, cut at proper intervals, to serve as a continued machicooly for defending the foot of the building: these loop-holes to be covered by shutters, except when actually used against an enemy. Both stories are also usually crenneled,

care being taken, that the lowest tier of loop-holes shall be cut at such a height, that an enemy, on advancing close to the bottom of the building, shall not be able to see into the interior, and fire conveniently upon the defenders, by means of their own loop-holes: a rule, which it is, however, proper to state, is not confined to blockhouses alone, but should be attended to in every kind of crenneled defensive work.* The foundation of a blockhouse should be of brick or stone, built substantially, and carried up some feet above the surface, whenever the proper materials are to be procured, and there is no pressure for time. A flat roof, properly secured against wet, and inclosed by a musquet proof timber parapet, is the best kind of covering that can be adopted for such buildings.

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* Loop-holes are usually made narrowest inside, this being generally considered the best method of constructing them; but in reality it seldom makes any great difference in the use of them, on what side they splay. If therefore their height is equal, on both sides of any crenneled work, it will be obvious, that the enemy's troops from without, as soon as they reach the foot of the wall, may take an equally good aim, through the loop-holes, and with equal effect, against the garrison of the work, as the latter can do in defending it. Consequently the assailants, by superiority of numbers, may force a work so constructed to surrender, even without penetrating into it. For this reason, loop-holes should either be constructed, close to the surface of the exterior ground, like those of the casemated caponier, represented in the second figure of page 384; or their soles should be raised at least 5 feet 6 inches above that level. In a blockhouse or defensible building, not provided with strong interior partitions, this precaution is more essentially necessary, because it will be evident, that if an enemy can conveniently fire into the loop-holes, they will be able to take one part of the defenders in reverse, whilst they oppose the others in front; so that, even with equal numbers, they must have the advantage. In the crenneled counterscarp galleries of works, whose ditches are properly flanked, it is of less importance on what level the loop-holes are placed, although it is always desirable that the above rule should be attended to, when circumstances will permit. It is the same consideration, which renders the drop before a casemated battery, absolutely necessary, whenever the embrasures are placed low.

The guns in blockhouses are fitted up with breech lashings, tackles, &c. on the same principle as on board ship, and may also be placed at the same intervals apart, in proportion to their nature. Carronades are more commonly mounted in blockhouses, than long guns. Generally speaking, about 12 feet per gun, is sufficient, so that for example a blockhouse of 50 feet square may have four embrasures or PORTHOLES * for cannon, on each side of it; it being observed, however, that when two adjoining sides of a blockhouse are engaged at the same time, one of those two guns, which are nearest to the angle, must remain inactive, as it cannot be fired without impeding the manœuvres of the other.

It will of course be readily understood, that blockhouses have not only the great disadvantage of being built of combustible materials, but are also, from their construction, incapable of resisting a common field battery of equal force. Notwithstanding these defects, they may however, under many circumstances, be of so much use, as fully to justify the erection of them in those countries, in which their expense is trifling.

There is another species of defensive work, which may be formed of timber, called AN ABBATIS, the nature of which shall next be explained.

A great number of trees are cut down, and placed in any given allinement, with all their trunks inwards, and the branches pointing outwards, the smallest and weakest of which are previously lopped off. It may easily be imagined, that a sufficient number of trees, put together in this manner, even loosely in the open field, will form a very serious obstacle to an enemy's troops: but to add to the strength of abbatis, it is usual to construct an earthen parapet and banquette for infantry, immediately in rear of the trunks of

* The term "porthole or port" is applied to a rectangular embrasure cut through woodwork, as for example in ships of war.

the trees, a part of which may be buried in the said parapet, so as to increase the solidity of the work.

Abbatis, although effectual against an attack by infantry, may be greatly injured, and in a certain time rendered unserviceable, by the fire of artillery. It is therefore common, when they are employed in the strengthening of earthen works, to place them in dry ditches, or in other situations covered from direct cannon shot. When an abbatis is constructed in a ditch, the trunks of the trees which compose it, may be fixed some feet in the ground, like palisades, and the general line of the whole may incline outwards, at an angle of about 45°, instead of being placed horizontally or nearly so, as in the former supposition.

Although abbatis, and the various other timber works, which have just been described, are most commonly used in temporary fortification; it was judged proper not to omit them here, because, in cases of emergency, they may often be applied, with equal propriety, to improve the defences, or to remedy the existing defects, of works of permanent fortification.

CHAP. XXIV.

OF THE STRENGTH OF REVETMENTS, AS OPPOSED TO THE PRESSURE OF EARTH.—VAUBAN'S GENERAL PROFILE ANALYZED.—SLOPING REVETMENTS, RECTANGULAR REVETMENTS, AND COUNTER-SLOPING REVETMENTS, COMPARED.—OF DEMIREVETMENTS OR PARTIAL REVETMENTS: AND OF LEANING REVETMENTS.

I shall now explain the principles, which ought to be kept in view, in fixing the dimensions of the revetments of a fortress.

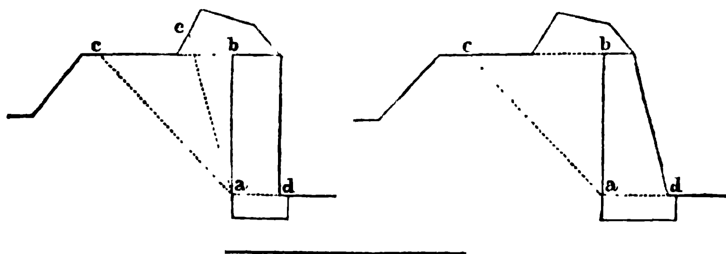
It has already been stated, that they should be of a certain height, in order to render it difficult for an enemy to take them by escalade. In determining their thickness, one of the principal

considerations is, to give them sufficient strength, to resist the great pressure of earth and rubbish, acting against the back of them, which has a constant tendency to overset the wall, and throw it forwards into the ditch.

Draw two sections of the rampart of a fortress, of equal height, making the revetment, in one rectangular, but in the other, let it have a slope in front, in the usual form; and let the base of the rectangular revetment be equal to the mean thickness of the sloping one: that is to say, let it be equal to one half of the thickness at top, and of the thickness at bottom, of the sloping revetment, added together.

Let the top of the revetment, and the foot of the interior slope of the parapet, be upon the same level, in both sections; and let the rampart and parapet be of the same dimensions, in both.

From the back of the base of each revetment, draw a dotted oblique line, a c, meeting the upper part of the rampart, and sloping in the proportion of 1 to 1. In one of the sections, only, from the same point, draw another oblique dotted line, a e, at a smaller slope. Mark the back of the top of each revetment by the letter, b, and the bottom of the front of each by the letter, d; and dot the base of your parapet in both figures.*



* In the succeeding parts of this chapter, a revetment continued up to the level of the base of the parapet, in the manner represented in these figures, shall be called a full revetment, although there may not always be a small exterior parapet-revetment above it, which is generally supposed to be the case, when the above term is used, at least if nothing is specified to the contrary.

It was stated, in a former part of this book, that earthen works, unreveted, cannot possibly stand perpendicularly, but must be formed with a certain slope, in order to insure their durability; that the looser kinds of earth require a greater slope, in proportion to their height, than stiff earth; and that, on an average, it has been found, that earth of a middling tenacity requires a slope of about 1 to 1, such as was represented in your figures, by the line, a c, to enable it to stand in a permanent form, for any length of time. Let us suppose that the ramparts, of which we have drawn the sections, are composed of earth of this last mentioned quality.

Then it must be evident, that, if there were no revetment, the whole of the earth of that part of each rampart, which is in front of the dotted line, a c, would be liable to fall; because it is partly perpendicular, and even if you were to slope off any portion of it, from the point, a, in the form, a e, for instance; such a slope would still be less than the proper or natural slope, a c, which, according to our supposition, is the smallest slope that will enable earth of the above quality to stand, or preserve its figure for a permanency.

Consequently the whole of that portion of the rampart, which is represented by the triangle, a b c, being supported in an unnatural position, may appear to press as a dead weight against the back of the revetment; and to this pressure a considerable addition must be made by the weight of the parapet, which also derives its sole support from the revetment, as will appear equally evident, by inspecting either of the figures.

The point, d, at the foot of the revetment, being on the level of the bottom of the ditch, is supported by the mass of ground in front of it, against the pressure in rear; and cannot be forced from its place. No other part of the revetment is so supported, and therefore, the tendency of the pressure of earth from behind is to overset the wall, by throwing it forwards upon the point, d, as on a pivot or fulcrum.

As far as regards the difference between your two sections, it is to be observed, that by constructing the front of a revetment with a slope, the pivot is thrown more forward, whilst the great weight or mass of the masonry, or in other words the center of gravity of the wall,* is kept more backwards, than would be the case in a rectangular wall, containing the same quantity of materials. The mass of masonry, contained in a sloping wall, does therefore resist the pressure of the earth behind it, with a longer lever, than could be done by the same mass, contained in a rectangular wall of equal height; and consequently, according to the principles of mechanics, the former is the strongest of the two.

For this reason, exterior slopes have almost always been considered proper, not only for the revetments of fortresses, but also for retaining walls, in civil works. The more early modern engineers usually gave their revetments a slope of one fifth. Afterwards one sixth was more commonly used. Latterly, it has, by many, been considered best to reduce it to a still smaller proportion, such as one eighth, one tenth, or one twelfth; and some writers of reputation have even recommended, that the slope should be suppressed altogether.

The reason urged is, that the seeds of vegetable matter, which seldom or never affect a perpendicular surface, generally insinuate themselves into the joints of sloping walls; where they take root, and by degrees ruin the face of the masonry. This remark may be proved, by daily observation, in the horizontal or sloping parts of common garden walls, &c.; and it has actually been found, that the revetments of fortified places, when constructed with great slopes, such as one fifth, are liable to considerable external injury from this cause, so that they require new pointing and facing, from

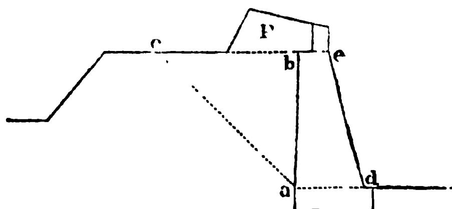
* For various useful propositions, relative to the center of gravity of bodies, see Dr. Hutton's Course of Mathematics. Vol. II.

time to time; a mode of repair, which never unites well with the body of the original work.

In practical arts, the surest rules are always derived from experience. Having noticed the general principles, according to which the strength of revetments ought to be regulated; I shall therefore proceed to state the actual dimensions, used by Vauban, who was employed in the construction and repairs of a very great number of fortresses; and whose walls are not, in any case, said to have failed.

He gave all his revetments an exterior slope of one fifth; and made them uniformly 5 feet 4 inches thick at top; so that their thickness at bottom would of course vary, in proportion to their height. He always used diminished counterforts, making their breadth at the tail, two thirds of their breadth at the root; and placing them at central intervals of from 15 to 18 feet apart. For a revetment 10 feet high, he allowed a counterfort 4 feet long and 3 feet wide at the root. For every additional 5 feet of height given to the revetment, he made his counterforts 1 foot longer, 6 inches broader at the root, and 4 inches broader at the tail. The general profile, thus regulated, will afterwards be more particularly explained by the first table of revetments (*See page* 501).

Vauban almost always constructed his ramparts with full revetments, surmounting the common scarp revetment by a small exterior parapet revetment. Draw therefore a rampart in that form, adding a dotted line, as in your last figures, to represent the natural slope of common earth, and let the point, where this line meets the upper part of your rampart, be marked by the letter, c. Mark the bottom of the revetment by the letters, a d, and the top of it by the letters, b e. Mark also the parapet by the letter P.



The solidity and weight of the scarp revetment, in our present

figure, will be represented by the area of the figure, a b e d; whilst the weight of earth, acting upon it, will be represented by the area of the triangle, a b c, added to that of the earthen part, P, of the parapet.*

If we suppose the small exterior revetment of the parapet to be 3 feet thick, and the total thickness of the parapet, at top, to be 18 feet; there will remain 15 feet, for the thickness, at top, of the earthen part of the parapet. Let us further suppose, that the parapet has an interior slope of one third, with a dip of one sixth of its thickness; then the exterior height of the earthen part of the parapet will be 5 feet. This number will also express the interior height of the small parapet-revetment; the exterior height of which will be 4 feet 6 inches.

Assuming these dimensions, the area or superficial contents of the earthen part of the parapet, P, will be 103·125 superficial feet; and the area of the small exterior revetment of the parapet will be 14·25 superficial feet, in all cases, whatever the height of the revetment may be. The contents of the triangle, a b c, will vary according to the height of the revetment. Let us suppose, for example, that the said height, represented in our figure by the line, a b, is 30 feet; b c will also be 30 feet, because the slope of a c is supposed to be in the proportion of 1 to 1. The area of the triangle, a b c, will therefore be equal to half the square of 30, that is to 450 superficial feet. Add this number to 103·125 the area of the earthen part of the parapet, before found, and the sum will be 553·125 superficial feet, which will represent the total quantity of earth, pressing upon the revetments.

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* Generally speaking, this applies to all the heights most commonly used for revetments; but if the height is much less than usual, as for instance, if a b is supposed to be less than 15 feet; then a part only of P must be included in the pressure, because the dotted line, a c, will not fall in rear of the parapet, but will cut off some portion of it, in the manner represented by the line, a e, in the first figure given in this chapter.

By referring to the first table of revetments, you will find that the mean thickness, of one of Vauban's scarp revetments 30 feet high, is 8 feet 4 inches. Multiply these numbers together, and the product, 250 superficial feet, will represent the total quantity of masonry in the scarp revetment of your figure.

The quantity of masonry in one of Vauban's scarp revetments, supposed to be 30 feet high, is therefore to the quantity of earth, pressing upon the back of it, as 250 to 553·125, or as 45½ to 100 nearly. But as we do not learn, that he ever dispensed with counterforts, in his scarp revetments, the above cannot be considered as the true proportion, between the quantity of masonry and the pressure of earth, in that Engineer's profile. We must therefore calculate, and add in a certain proportion, for the contents of the counterforts; and we must also take into consideration the small exterior revetment of the parapet, before we can arrive at a true conclusion.

In a revetment 30 feet high, the length of Vauban's counterforts, according to the Table, is 8 feet, and their mean width 4 feet 2 inches. Multiply these three dimensions together, and you will find a result of 1000 cubic feet, for the solid content of each counterfort.

Vauban's counterforts are placed from 15 to 18 feet apart, according to circumstances. Their mean distance from center to center may therefore be considered equal to 16½ feet. An additional mass of 1000 cubic feet of masonry being therefore added to every sixteen feet and a half, in length, of the revetment; if you divide 1000 by 16½, the quotient is 60·606 superficial feet; which will represent the mean quantity of masonry, added to the area of the revetments in general, by the counterforts.

Again, if the above result is divided by 30, the height; the quotient will be 2·0202 or 2 feet 0¼ inch nearly, which shows the mean thickness, that would be added to the revetments, by the total quantity of masonry, contained in the counterforts; if,

instead of being built in that form, it were applied to the back of the scarp revetment, in one continued mass.* Adding therefore 2 feet 0¼ inch to 8 feet 4 inches, which, according to the Table, is the mean thickness of masonry in one of Vauban's revetments 30 feet high, the sum will be 10 feet 4¼ inches, and this will represent the mean thickness of a wall 30 feet high, supposed to be built without any counterforts; and composing a mass of masonry, equal to the whole of that, which is contained in Vauban's scarp revetment and its counterforts, added together.

It was before stated, that the quantity of masonry, contained in the scarp revetment of our profile, is represented by 250 superficial feet; that the mean quantity of masonry, added to this by the counterforts, is 60·606 superficial feet; and that the quantity of masonry, contained in the small exterior revetment of the parapet, is 14·25 superficial feet. These numbers, added together, amount to 324·856 superficial feet, which will consequently represent the total quantity of masonry, employed in one of Vauban's profiles, 30 feet high.

The proportion, therefore, between the quantity of masonry and the pressure of earth, acting upon it, in one of Vauban's profiles of the above height, will be as 324·856 to 553·125; or as 58·731 to 100 nearly.

Upon similar calculations, has been formed the second Table of revetments, which is a kind of analysis of Vauban's general Profile.

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* RULE. To find the mean thickness of masonry added to any profile by the counterforts, by a shorter method. Multiply the length of the counterforts by their mean width, and divide the product by their distance from center to center.

Thus for example, in Vauban's scarp revetments, 30 feet high, multiply 8 the length of the counterforts, by 4 feet 2 inches, their mean width; and the product 33⅓ feet, divided by 16½ feet, the mean distance of the counterforts from center to center according to the Table, will yield a quotient of 2 feet 0¼ inches nearly as before. The longer method, given in the text, was merely inserted for the sake of clearness, it being more explanatory.

TABLE I.

*Dimensions of Vauban's General Profile for Full Scarp Revetments.**

Height of the walls.	REVEVTMENT. Thickness at top.		Thickness at bottom.		Mean thickness.		COUNTERFORTS. Length.	Mean width.		Actual width at the root.		Width. at the tail.		Distance from center to center.
Feet.	Feet.	Inches.	Feet.	Inches	Feet.	Inches	Feet.	Feet	Inches	Feet	Inches.	Feet	Inches.	Feet.
10	5	4	7	4	6	4	1	2	6	3	0	2	0	From 15 to 18
20	5	4	9	4	7	4	6	3	4	4	0	2	8	
25	5	4	10	4	7	10	7	3	9	4	6	3	0	
30	5	4	11	4	8	4	8	4	2	5	0	3	4	
35	5	4	12	4	8	10	9	4	7	5	6	3	8	
40	5	4	13	4	9	4	10	5	0	6	0	4	0	
50	5	4	15	4	10	4	12	5	10	7	0	4	8	
60	5	4	17	4	11	4	14	6	8	8	0	5	4	
70	5	4	19	4	12	4	16	7	6	9	0	6	0	
80	5	4	21	4	13	4	18	8	4	10	0	6	8	

* The dimensions of the counterforts, contained in Vauban's general profile, vary according to their height, and therefore, in framing the table, it was not judged necessary to reduce the above dimensions from French to English measure, as the same proportions will very nearly hold good in both. With respect to the thickness at top of his revetments, this was necessarily reduced to English measure, because he has thought proper to assume a certain fixed dimension for it, without any regard to the height, to which it consequently does not, in any two cases, bear the same proportion.

TABLE II.

Vauban's General Profile of Full Scarp Revetments analyzed.

Height of the walls.	Mean thickness of the scarp revetment.		Mean thickness of a wall, equal to the scarp revetment and counterforts added together.		Quantity of masonry in the scarp revetment.	Mean quantity of masonry in the counterforts.	Quantity of masonry in the small exterior revetment of the parapet.	Total quantity of masonry in the scarp and parapet revetments and counterforts added together.	Quantity of earth pressing on the revetments.	Proportion of the total quantity of masonry to the pressure of earth.		Cubic yards of masonry contained in one running yard of rampart.
Feet.	Feet.	Inches.	Feet.	Inches.	Superfic Feet	Superfic. Feet	Superfic Ft	Superficial Feet.	Superfic. Feet	As	To	Cubic Yards.
10	6	: 4	6	: 11¼	63·333	6·060	14·25	83·644	142 65	58·635	to 100	9·293
20	7	: 4	8	: 6½	146·666	24·242	14·25	185·159	303·125	61·083	to 100	20·573
25	7	: 10	9	: 0¼	185·833	39·772	14·25	239·856	415·625	57·709	to 100	26·650
30	8	: 4	10	: 4¼	250·000	60·606	14·25	324·856	553·125	58·731	to 100	36·095
35	8	: 10	11	: 4	309·166	87·500	14·25	410·916	715·625	57·420	to 100	45·657
40	9	: 4	12	: 4⅓	373·333	121·212	14·25	508·795	903·125	56·337	to 100	56·533
50	10	: 4	14	: 7	516·666	212·121	14·25	743·038	1353·125	54·912	to 100	82·559
60	11	: 4	17	: 0	680·000	339·394	14·25	1033·644	1903·125	54·313	to 100	114·849
70	12	: 4	19	: 7¼	863·333	509·091	14·25	1386·674	2553·125	54·312	to 100	154·075
80	13	: 4	22	: 5	1066·666	727·273	14·25	1808·189	3303·125	54·741	to 100	200·909

The last column in the second table, which states the quantity of cubic yards of masonry contained in one running yard of rampart, has been added for the purpose of enabling the reader to form an expeditious estimate of the average quantity of masonry required for the scarp revetments of a fortress of any extent.

For example, by referring to the first Table in Chap. XVI, (*See page* 324.) it will be found, that the length of the outline of a front of fortification of 384 yards exterior side, with a perpendicular of 64 yards, and faces of 110 yards, is 482·6 yards. If we suppose the fortress to be a hexagon, the above number, multiplied by 6, gives 2895·6 for the total length of the scarp revetments of the main inclosure, in yards. But if the walls are 30 feet high and constructed according to Vauban's general profile, there will, by the second table of this chapter, be 36·095 cubic yards of masonry in each running yard of rampart. Multiply, therefore, the numbers 2895·6 and 36·095 together, and after striking out superfluous decimals, the product will be 104,516 nearly, which shows the total number of cubic yards of masonry, that will be required for building the whole of the scarp revetments and counterforts of the body of the place of the supposed hexagon, according to the said profile. It will be evident, that a similar combination of the various tables, contained in Chap. XVI, and in our present chapter, may be easily applied to a great variety of other cases; and therefore more examples may be deemed superfluous.

Some writers on fortification, in treating of this part of their subject, have laid down as a rule, that the scarp revetment alone, without the assistance of counterforts, should, in all cases, be in exact equilibrium with the pressure of earth nearly; and just capable of resisting it. And that, after this point is determined, counterforts should be added, also bearing some invariable proportion to the pressure, in order to insure the durability of the walls, and to give them, at all heights, a certain fixed preponderancy over the force which acts upon them: so that the strength

of the total mass of masonry shall, in every part of the fortress, be greater in the said proportion; as, for instance, that it shall be greater by one half, or by one third, than what is absolutely and barely necessary for resisting the pressure. Reasoning on the above principle, many authors have censured Vauban's general profile, as contained in the foregoing tables, alleging, that his revetments, in low profiles, are unnecessarily strong: but that, in high profiles, they are a great deal too weak, in proportion to the pressure of earth acting upon them.

For example, by referring to the last Table, you will find, that in walls 20 feet high, the masonry contained in Vauban's scarp revetment is to the pressure of earth, as 146·666 superficial feet to 303·125, or as 48·385 to 100 nearly: whereas in walls 80 feet high, the proportion of the masonry contained in his scarp revetment is to the pressure of earth, as 1066·666 to 3303·125, or as 32·292 to 100 nearly: the revetment being stronger by about one half, in proportion to the pressure, in the former case, than in the latter.

Again, by further examining Vauban's general profile, it will appear, that there is no fixed proportion between the strength of his scarp revetments and that of his counterforts: for in his low profiles, the mass of masonry, contained in the former, bears a much greater proportion to that, which is contained in the latter, than in his high profiles; and in no two different heights is it the same.

For example, in walls 10 feet high, it appears by the second table, that the scarp revetment is to the counterfort, as 63·333 superficial feet to 6·06, that is to say, the revetment is more than ten times greater than the counterfort. In walls 20 feet high, the scarp revetment is about six times greater than the counterforts: in walls 40 feet high, it is about three times greater: in walls 60 feet high, it is about twice as great: but in walls 80 feet high, the scarp revetment is only greater, by one half, than the counterforts.

As Vauban must, therefore, have acted upon quite a different principle, from those, who recommend that the revetment and the counterforts shall, in all cases, bear nearly the same given ratio to each other, whatever the height may be: it seems by no means fair, that these authors should decide upon the merit or strength of his general profile by their own rules, in the manner before mentioned. We are not informed, that, in any instance, that Engineer ever built his revetments without counterforts; and therefore the only just method of judging of the strength of his walls, is to consider his revetments and counterforts not separately, but as combined together, and forming only one and the same mass, which is always the case in reality, when the masonry is good. And if the subject is thus considered, Vauban's general profile will not appear to be so very inconsistent with itself, at different heights, as is pretended by the writers before alluded to.

For example, by the second table, it will be seen that in walls of from 20 to 35 feet, which comprehend the heights most generally used in the revetments of fortresses, the proportion of the total quantity of masonry in Vauban's general profile, when compared with the pressure of earth, varies only between the ratio of 61·083 to 100, and the ratio of 57·42 to 100, which difference is by no means considerable; and even if we take those two ratios, given in the same table, which are the most discordant with each other; the masonry of the one is only stronger in proportion by about one eighth, than that of the other.

Still as there is a difference of ratio, at different heights, which although not very great, may certainly be considered as a defect in Vauban's general profile; it may be deemed best, instead of following implicitly the rules laid down in his tables, to adopt from amongst the various ratios, used by him, that which is the least expensive, of all those whose strength has been fully proved by experience. Now it is well known, that Vauban's revetments were generally about 32 feet high, measuring from the level of the ditch

to the cordon, that is to say without including the small exterior revetment of the parapet. He may occasionally have made his revetments lower, but seldom or never much higher than the above dimension. We may therefore call 30 feet the average height. But by the second table, it appears that at the height of 30 feet, the total quantity of masonry in Vauban's general profile is to the pressure of earth as 58·731 to 100. Without regarding the ratios used by him, at other heights, greater or less than the above, this therefore may be assumed as a good proportion to follow in practice; that is to say, if at any height of profile whatsoever, we make the strength of our masonry to the pressure of earth acting upon it in the same proportion, namely as 58·731 to 100 nearly, we shall run no risk of failure.

In some cases, however, it is to be observed, that Vauban admitted of a deviation from the proportions, stated in his general profile. If, for instance, the masonry used in constructing a fortress, was of a bad quality, he recommended the thickness, at top, of the scarp revetment, to be increased to 5 feet 10 inches. If, on the contrary, the masonry was remarkably good and strong, he then allowed 4 feet 10 inches only, for the thickness, at top, of his scarp revetment; which is 6 inches less than the dimension laid down in the table. In some of his works, the small exterior revetments of the parapets were either dispensed with, or afterwards pulled down; and yet no failure ensued. Supposing all these diminishing circumstances to take place in a revetment of 30 feet high, and that the counterforts are built at intervals of 18 feet from center to center, which we are told was the practice most commonly followed by Vauban; then instead of the proportion laid down in the table, the total quantity of masonry of such profile would be to the pressure of earth as 290·555 to 577·5, or as 50·312 to 100 nearly.

Moreover it appears, that other Engineers, who have subse-

quently been employed in the construction of fortresses, whilst they adhered to Vauban's general profile in other respects, have usually diminished the slope of their revetments from one fifth to one sixth, without making any addition to the thickness at top, on that account. In a revetment 30 feet high, this construction also diminishes the total quantity of masonry to the last named ratio; and yet we do not hear that, in any instance, it has been found too weak.

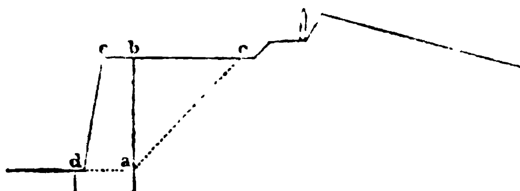
Upon the whole, it follows, that if the quantity of masonry in any profile is made to the pressure of earth, as 58·731 to 100, it will be perfectly strong in almost all cases; that in many cases, it may even be diminished, so as to bear to the pressure a proportion of 50·312 to 100: but it certainly would not be prudent, in ramparts composed of common earth, to make the revetments much weaker than the last named ratio, as we have not experience to guide us, and there might be a risk of failure.*

Having so far explained the general rules, which ought to be kept in view, in the construction of scarp revetments; we shall next proceed to treat of the rules, that apply to the counterscarp revetments of a fortress, and to the gorge revetments of outworks.

Draw a figure to represent part of the ditch of a fortress, with the covered way and glacis in front of it; introducing a counterscarp revetment, but without any counterfort. Mark the top of the said revetment by the letters, e b: mark the bottom of it by

* I made use of the expression "common earth," because there are some kinds of soil, on which a fortress may be built; such as chalk, &c. which will of themselves stand nearly perpendicularly, and yet which it is proper to revet. In such soils, revetments considerably weaker, even than the last named ratio, might suffice, as far as the pressure alone is concerned. For these cases, no precise rules can be given before hand, as they may admit of great variety; and therefore much must depend upon the judgment of the Engineer employed.

the letters, d a; and draw a dotted line, a c, sloping upwards, in the proportion of 1 to 1, in order to mark the extent of the pressure of earth, acting against the back of the revetment.



As the breadth of the covered way of a fortress is always considerably greater than the height of the revetment; the dotted line, a c, must either terminate in rear of the banquette, in the manner represented in our present figure, or, at all events, it would only include a small portion of it. In counterscarp revetments, therefore, generally speaking, the pressure of earth may be, in most cases, represented by the triangle, a b c; at least it can never exceed that proportion, except in a very inconsiderable degree: and in the gorge revetments of works, it may always be represented by the said triangle. Although neither the covered way of a fortress, nor the interior of any other work, are ever made exactly horizontal; we shall, in the present part of our subject, suppose them to be so, for the sake of clearness, as the difference is usually very trifling, and therefore not worthy of notice, in the calculations, which are now about to be made. Under this supposition, by reason of the nature of the slope of the line, a c; the length, b c, will be equal to a b, the height of the revetment.

The superficial contents of the triangle, a b c, will in all cases, therefore, be equal to half the square of a b. Consequently, if we suppose our counterscarp revetment to be 20 feet high, the pressure of earth, acting on the back of it, will be represented by 200 superficial feet.

By analyzing Vauban's general profile, we before came to a

conclusion, that if the walls of a fortress, (counterforts included,) are to the pressure of earth, acting upon them, as 58·731 to 100, they will be sufficiently strong. To find the strength of masonry, necessary to support the earth, in our present profile, we must therefore say, as 100 superficial feet, are to 58·731; so are 200 to 117·462. The last-mentioned number, thus found, indicates the superficial contents of the profile of a revetment 20 feet high, necessary for supporting the pressure of earth of a simple terre-plein without any parapets; such as acts upon counterscarp and gorge revetments.

This point being determined, divide 117·462 by 20; and the quotient 5·8731, or 5 feet 10½ inches nearly, shows the mean thickness of a wall, of the above height; which shall be equal to a proper counterscarp revetment and to its counterforts, also supposed to be of the same height, added together.

In order to find the thickness, at top, of a sloping wall, containing the same quantity of materials, you must next deduct half the base of the given slope from the mean thickness.

For example: if you suppose the wall to have a slope of one fifth, the base of this slope, in a revetment 20 feet high, is 4 feet. Deduct 2 feet, which is one half of the above base, from 5 feet 10½ inches, the mean thickness; and the remainder 3 feet 10½ inches will give you the thickness, at top, of a wall, having a slope of one fifth, and capable of supporting the pressure of earth of a simple terreplein without any parapet.*

Upon similar calculations has the following table been formed.

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* 5 feet 10½ has been assumed in calculating the following table, although the real proportion falls a little short of that dimension.

TABLE III.

Dimensions of Counterscarp Revetments, or others, intended to support Simple Terrepleins without Parapets.

Height.	Mean thickness of masonry, equal to the revetment and counterforts, added together.			Slope 1-5th. Thickness at top of a sloping wall, equal to the above.			Slope 1-5th. Thickness at bottom of Do.			Quantity of masonry.	Pressure of earth.	Proportion of the quantity of masonry to the pressure of earth.		Cubic yards of masonry, contained in one running yard of revetment.
Feet.	Feet.		Inches.	Feet.		Inches.	Feet.		Inches	Superficial Feet.	Superficial Ft.	As	To	Cubic Yards.
10	2	:	11¼	1	:	11¼	3	:	11¼	29·375	50	58·75	to 100	3·2638
20	5	:	10½	3	:	10½	7	:	10½	117·5	200	Do.	to Do.	13·0555
25	7	:	4⅛	4	:	10⅛	9	:	10⅛	183·59375	312·5	Do.	to Do.	20·3993
30	8	:	9¾	5	:	9¾	11	:	9¾	264·375	450	Do.	to Do.	29·375
35	10	:	3⅜	6	:	9⅜	13	:	9⅜	359·84375	612·5	Do.	to Do.	39·9826
40	11	:	9	7	:	9	15	:	9	470·0	800	Do.	to Do.	52·2222
50	14	:	8¼	9	:	8¼	19	:	8¼	734·375	1250	Do.	to Do.	81·5972
60	17	:	7½	11	:	7½	23	:	7½	1057·5	1800	Do.	to Do.	117·5
70	20	:	6¾	13	:	6¾	27	:	6¾	1439·375	2450	Do.	to Do.	159·9305
80	23	:	6	15	:	6	31	:	6	1680·0	3200	Do.	to Do.	186·6666

The pressure of earth, in our last profile, is always represented by the right-angled triangle, a b c; and this triangle having its base and height equal,* in all cases, no matter how high or how low the profile may be; the said pressure is consequently represented, at all possible heights, by figures similar to each other. And for this reason, the thickness and height of the walls, calculated in our last table, are in all cases in the same proportion to each other.

In walls of fortification, on the contrary, which are to support a parapet in addition to the terreplein; the figures, which represent the total pressure of earth, cannot possibly be similar to each other, at any two different heights; because the parapet, which forms a part of the above pressure, remains of the same invariable dimensions nearly, in the highest as well as in the lowest profiles. For this reason, in scarp revetments, even although calculated on the justest principles, the mean thickness of masonry, and the height of the revetment, will never be in the same proportion to each other, at different heights.

It was before observed, that the strength of masonry, in Vauban's general profile, does not appear to be exactly proportioned to the pressure, in all cases: for this reason it was judged best to construct the last table, rather according to his practice than to his theory; and therefore the dimensions, laid down in this table, which is calculated for walls without parapets, are, in high profiles, stronger than those of Vauban's general profile; although the latter has, in all cases, a greater pressure of earth to support. It is only in walls of 30 feet that they will be found nearly to agree.†

* If the line, a c, had a different slope from what is supposed in the text, the base and height of the triangle, although not equal, would be proportional, in all cases, so that the same result would still follow.

† It was stated, that in many cases, in scarp revetments of 30 feet, the masonry had been found strong enough, when bearing to the pressure of

I shall here remark, that two advantages arise, in fortification, from the use of counterforts. In the first place, a wall built with counterforts has a greater base, and consequently more stability than another wall, containing an equal mass of masonry, but having no counterforts; for, in the former case, the center of gravity of the whole mass of masonry is thrown a great deal more back, than in the latter case, and therefore it resists the pressure of earth, which tends to overset it, with a much longer lever. In this view of the subject, it will appear that of two different counterforts supposed to be of the same height, and also equal to each other in solid contents; that which is the longest will be the most advantageous.

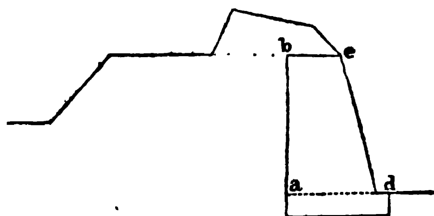
Secondly, it is more difficult to effect a practicable breach, by means of battering guns, in a fortress, whose revetments are backed by counterforts, than when there are none.

In our last table, the dimensions of walls without counterforts only are given. But as this mode of building is not to be recommended, in works of fortification, I shall next state the method of determining the dimensions of revetments and of their counterforts, which, when added together, shall be equal to the above. The solution of this question depends upon such very obvious principles, that it may perhaps seem quite superfluous to offer any explanation of it. In conformity, however, with the general plan of this work, which has been to place every thing in the clearest and simplest point of view, I judged it best not to omit it.

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earth a ratio of 50·312 to 100 only. If Table III. had been calculated according to this last-mentioned ratio, then the mean thickness proper for a revetment of 10 feet high, would have been about 2 feet 6¼ inches only. and the mean thickness, at any other height, would have been in the same proportion. In a revetment 30 feet high, for example, the mean thickness ought, according to this proportion, to be 7 feet 6¼ inches.

Draw a simple revetment without any counterfort, in order to represent the given wall: and mark the top and bottom of it, by the same letters, b e, a d, used in your former figures.



The front of our given revetment may be supposed to have a slope, but the nature of this slope, and indeed whether it has any slope or not, is of no importance in the following question. The only thing, necessary to be considered, is the thickness at top, b e, of the wall, which we shall suppose to be of any given dimension, such as 8 feet 6 inches, for instance.

Let us next suppose, that after due consideration, we fix upon any dimension, rather smaller than the above, 6 feet for example, as the proper thickness at top for another proposed revetment, which is to be built with counterforts, in such a manner as to form, by means of the said counterforts included, a mass of masonry exactly equal to that of our given revetment. (*See the next figure.*)

Upon the top of your given revetment, set off, from front to rear, a space, e f, equal to 6 feet; and draw the dotted line, f h, parallel to the back of the said revetment.

This being done, the space, h f e d, will represent the dimensions, which are to be given to your proposed revetment; whilst the remaining space, a b f h, the thickness of which is 2 feet 6 inches (*this being equal to the difference between* 8 *feet* 6 *inches and* 6 *feet*), will represent that portion of the masonry of your original revetment, which is to be thrown into counterforts, in constructing your new profile.

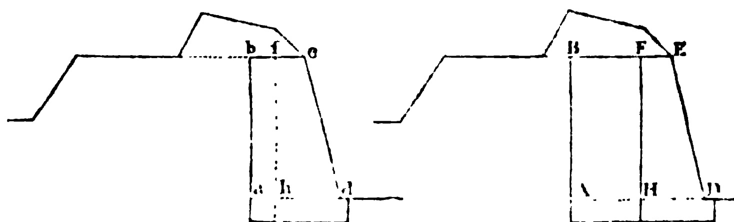
Draw a new section, having the parapet, terreplein, &c. of the same dimensions as in your former figure; but let the revetment be

smaller, making it exactly equal to the portion, h f e d, of your first revetment, and mark it in the same manner, but with capital letters, for the sake of distinction.

The figure, H F E D, thus drawn, will represent the revetment of your new profile proposed. It only remains to determine the size of the counterforts; and these, according to the supposition, are to be equal to the mass of masonry, contained in the portion, a b f h, of your first revetment.

The line, b f, being 2 feet 6 inches, as was above stated, the length of each of the proposed counterforts may be made any number of times greater than the above, that may be judged convenient, as for instance four times greater.

In rear of the revetment of your new profile, you will therefore draw a counterfort, making it of the same height as the revetment, and 10 feet long, which is four times the length of b f. And in order to show, that it corresponds with the portion, a b f h, of your original revetment, mark it in the same manner, but with capital letters.



Then, as the section of the counterfort, A B F H, in your second figure, is four times greater than the section of the portion of revetment, a b f h, in your first figure; it will be evident, that whatever may be the width chosen for each counterfort of your new revetment, the distance from center to center of every two adjoining counterforts must be made exactly four times the above width; in order that the total mass of masonry, contained in the various counterforts of your new revetment, may be exactly equal

to that, which is contained in the continued portion, a b f h, of your original given revetment.

For example, if we suppose our counterforts to be each 5 feet wide, which is a good proportion, then the distance from center to center must be exactly 20 feet, or four times the above thickness; which will leave an interval of 15 feet in the clear, between every two adjoining counterforts.

But if, instead of 10 feet, the counterforts had been made 7 feet 6 inches long, which is only three times the length of the line, b f; and if we further suppose, that they had each been made 6 feet wide, instead of 5: then their distance from center to center would require to be 18 feet, this being three times the width of one of these new counterforts.

It will be unnecessary to add any further examples, as it may easily be conceived, from what has already been said, that the dimensions of counterforts, and the intervals between them, may admit of almost infinite variety, without making any difference in the quantity of masonry, used in the construction of them.

It was stated, that, for a reason before assigned, which seems founded upon just grounds, it has been recommended, that the exterior slope of revetments should be greatly diminished; and that some writers have even gone so far as to propose, that it should be entirely done away. In urging the above deviation from the common system, they do not however intend, that their profile should become rectangular, or perpendicular in rear. On the contrary, they recommend, that this new kind of revetment shall be built of the same thickness, both at top and bottom nearly, as laid down in Vauban's general profile; so that what the masonry loses in slope towards the front shall be transferred to the back of the wall. The nature of this species of revetment shall next be taken into consideration.

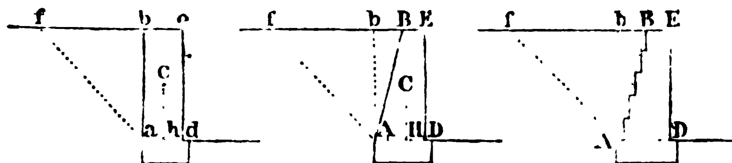
Draw two sections of gorge revetments of the same height,

making the one rectangular; but let the other have a slope in rear: and let the thickness of the rectangular revetment be equal to the mean thickness of the sloping one, so that the quantity of masonry in both shall be equal.

Mark the rectangular revetment, by the letters, a b e d: mark the sloping revetment by the capital letters, A B E D, and in both figures, draw dotted lines, a f and A f, in the usual manner, in order to show the extent of the pressure of earth. From the back of the base of the sloping revetment, you will also draw a dotted vertical line meeting the surface in the point, b.

Draw a third figure, similar to the second in every respect, excepting that the back of the slope, A B, must be dotted: in front of which, but near it and touching it, draw any convenient number of steps, and let the breadth and height of each step, be in proportion to the base and height of the slope, A B.

Lastly, from those points, c, and C, in your two first figures, which may represent the center of gravity of the masonry, drop dotted perpendiculars, meeting the base of their respective revetments, in the points, h and H.



In the first of the above figures, the pressure on the revetment is represented by the triangle, a b f: whereas in the second figure, it is represented by two triangles, namely, by the triangle, A b f, which is equal to the former, and an additional triangle, A b B.

It is to be remarked, that the slope in rear of the revetment, represented in our second figure, being of a contrary nature to that which is usually given to revetments in general, is called A COUN-

TERSLOPE; and for the same reason, the said revetment is styled A COUNTERSLOPING REVETMENT, by way of distinction.*

To return to the consideration of our figures, if we suppose the lines, a f, and A F, in each, to slope in the proportion of 1 to 1, as we have usually hitherto done; then the line, b f, will be equal to the height, A b; and as, by supposition, b B, in our second figure, is equal to one fifth of the height, it will, of course, also be equal to one fifth of b f. Therefore, in the two triangles, A b B, and A b f, the height of both being equal, and their bases being in the proportion of 1 to 5; the area of the small triangle, A b B, will be exactly one fifth of the area of the larger triangle, A b f.

Consequently, under the supposition, that the earth of our sections will stand at a slope of 1 to 1, the pressure of earth upon the sloping revetment, A B E D, will be greater, by one fifth, than that which acts upon the rectangular revetment, a b e d, supposed to contain the same quantity of masonry: and if the slope of the revetment in the second figure had been greater or less than one fifth, the additional pressure of earth, acting upon it, would also have varied in the same proportion.

But it is to be observed, that the additional triangle of earth, A b B, which acts upon the countersloping revetment, A B E D, does not only press obliquely but also vertically upon the back of the wall, A B; whereas there is no vertical pressure whatever on

* When any part of a work of fortification whatever is formed with a slope, contrary to the usual one, the same term "counterslope" is applied to it. Thus, for example, if the dip of a parapet were laid out towards the rear, so that the exterior crest of the parapet became the highest part of the work; the top of the parapet would be said to be formed with a counterslope; a method, which is sometimes followed in constructing mortar batteries. The soles of the embrasures of howitzer batteries are also frequently constructed with a counterslope. Carnot, a French Engineer (more known as a revolutionary leader), in his late treatise on the defence of fortresses, recommends a countersloping glacis.

any part of the rectangular revetment. And as all vertical or perpendicular pressures must evidently add stability, whilst oblique or lateral pressures only can tend to overset; it follows, that the triangle, A b B, may by its vertical pressure tend fully as much to strengthen, as it does by its oblique pressure to weaken, the countersloping revetment, represented in our second figure. Consequently, although the total quantity of loose earth, supported by the rectangular revetment, is certainly considerably less than that which is supported by the countersloping revetment, yet the actual force tending to overset the wall is by no means greater in our second profile than in the former: indeed it may most probably be somewhat less, for it is reasonable to suppose, that the mass of earth, A b D, must, in consequence of the natural power of gravity, press with much greater force vertically downwards, than in an oblique or lateral direction.

It was before stated, that in walls containing an equal quantity of masonry, such as those of our present figures, the actual strength of each, in opposition to the pressure of earth, will be more or less, in proportion as the great mass or weight of the masonry is thrown more or less to the rear. According to the rule, usually laid down, the strength of the revetments, a b e d and A B E D, will therefore be in the same ratio, as those portions, h d and H D, of the base of each, which are in front of the two points, h and H, where the said bases are intersected by vertical lines dropped from their respective centers of gravity, c and C.

In the rectangular revetment, h d, will in all cases be equal to half the base or thickness. In the countersloping revetment, on the contrary, the point, H, will vary its position, not only according to the slope, but also according to the height and thickness of the wall. We must therefore assume certain specific dimensions for our two revetments, before we can determine the relative proportion between the corresponding lines, h d, and H D.

Let us suppose the height of each revetment to be 30 feet, and

the thickness of the rectangular revetment to be 8 feet. As the other is supposed to have the same mean thickness, with a slope in rear of one fifth; the thickness at top, B E, of the sloping revetment, will of course be 5 feet; and its thickness at bottom, A D, will be 11 feet. Then, whilst the distance, h d, in the rectangular revetment is equal to 4 feet, it will be found, by calculation, that the distance, H D, in the countersloping revetment, will be equal to 4·1875 feet.

Hence, on reducing the thing to calculation, it appears that the strength of the rectangular revetment, a b e d, is to that of the countersloping revetment, A B E D, as 4 feet to 4·1875 feet, or as 24 to 25 nearly: so that the latter may be considered stronger than the former, by at least one twenty-fourth part. I use the expression "at least," because from the peculiar mode, in which the earth rests upon the back of the countersloping revetment, and which as before stated may be favourable to the stability of the masonry, it is probable that this profile exceeds the rectangular one, in proportional strength, by some ratio greater than the above.

We shall next compare the strength of our rectangular revetment, a b e d, with that of a common sloping revetment of the same height and mean thickness. The latter may also be represented by the trapezoid, A B E D, in our second figure, with this difference only, that the earth shall now be supposed to press against the perpendicular side of the wall, D E, instead of the sloping side, A B, and consequently whilst the strength of masonry of the profile, A B E D, when supposed to be used as a countersloping revetment, was in proportion to the line, H D, its strength, if converted into a sloping revetment, will of course be in proportion to the line, A H, which will be found by calculation to be equal to 6·8125 feet.

The strength of the rectangular revetment, a b e d, which is supposed to be 30 feet high and 8 feet thick, is therefore to that of a

sloping revetment, A B E D, of the same height and mean thickness, as h d to A H, or as 4 feet to 6·8125 feet, or as 24 to 41 nearly; that is to say, a rectangular wall of the above description is weaker by almost one half, than a sloping wall of equal height and containing an equal quantity of masonry: and it was before shown, that it is also inferior in strength to a countersloping wall, under the same supposition.

Those writers, who recommend the use of countersloping revetments, are of opinion, that instead of laying out the back, A B, in one continued slope, according to a right line, as in the second figure, it ought to be built with a certain number of steps or offsets, in the manner represented in the third figure. This form, they conceive, will greatly increase the power of resistance of the masonry, because they allege that, as the mass of earth, comprehended between the lines, A b, and b B, and the steps which compose the back of the wall, presses perpendicularly downwards upon the tread of the said steps, it will be impossible for the revetment to be thrown over upon the pivot, D, without forcing upwards the whole of the above weight. It appears to me, however, that this supposition is in some degree fallacious, for if the particles of earth are loose, they may be separated from each other by any adequate force; and therefore it may perhaps more reasonably be concluded, that in performing the supposed movement of falling forwards, instead of having to raise any very great part of the mass of earth in rear, the revetment shown in our third figure, would only have to tear away from the remainder of the said mass a certain inconsiderable portion of it, not much exceeding the sum of those small triangles, which lie between the steps and the dotted line, A B. Whether this would add to the stability of the masonry, so as to render our third profile in any great degree stronger than the second one, may be considered doubtful; but it is to be remarked, that in all cases the formation of the back of a countersloping revetment with steps would be much more convenient to the

workmen employed in building it; so that this construction should invariably be adopted in practice, in preference to a continued slope.*

We shall next take into consideration, the strength of profile necessary for demirevetments, or partial revetments.

Draw three figures, to represent demirevetments, giving to one of them a broad berm, to the second a narrower berm, but make the third without a berm; and let the height of the demirevetment, and the dimensions of the rampart and parapet, be the same in all; and dot the base of each parapet.

In rear of each demirevetment, draw also an oblique dotted line, in the usual manner, to represent the extent of the pressure of earth; and in the first figure, which has the broadest berm, let the above line produced agree with the front of the earthen part of the scarp.

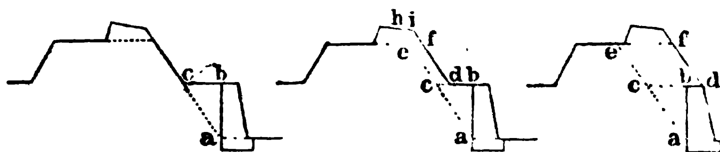
Mark the triangle, comprehended between the back of the demirevetment, the oblique dotted line, and the level of the berm, in each figure, by the letters, a b c, in the usual manner.

In the second figure, mark the exterior slope of the parapet by the letters, i f, placing the former at top; and mark the point, where the oblique dotted line intersects the base, and top of the parapet, by the letters, e and h.

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* In the text, I have only stated and commented upon that argument, in favour of offsets or steps in rear, which I have seen used by those Authors, who recommend countersloping revetments. There is however another reason, that might be urged in behalf of this construction. By the principles of mechanics, any power which presses or strikes upon a body, acts with the greatest possible effect, when it meets a perpendicular surface. Consequently the vertical pressure of the mass of earth, A b B, in our third figure, by acting perpendicularly upon the tread of the steps, may be supposed to exert a much greater power of strengthening the revetment, than if it acted upon an oblique surface, such as the line, A B, in the second figure.

In the third figure, mark the upper extremity of the oblique dotted line, by the letter, e.



By comparing these figures, it will appear, that in the first, by reason of the great berm, the total pressure of earth, acting upon the demirevetment, is represented by the triangle, a b c; so that according to this construction, neither the parapet, nor those parts of the rampart, which are above the level of the berm, do, in any degree, press upon the masonry. This advantage, however, could not be fully gained, in fortresses founded in common earth, without making the berm of a very inconvenient breadth; for example, if a b is supposed to be 20 feet high, the berm would require to be rather wider than the above proportion; and, even in the most tenacious kinds of soil, it could not be made much less than 12 feet, consistently with the above object.

In the second figure, in addition to the triangle, a b c, there is also a pressure upon the demirevetment, resulting from the weight of a part of the rampart, c e f d; as also from a portion of the parapet, e h i f. Consequently, the pressure of earth, in this profile, is greater, than in the former, by reason that the berm is narrower.

In the third figure, in which there is no berm, it will appear, that the pressure is by far the greatest of all; for, in addition to the triangle, a b c, there is the whole of the parapet, and a portion of rampart, c e f d, much greater than that, which is marked by the same letters, in our second figure.*

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* Even in profiles, constructed according to the third figure, it must, however, be remarked, that the dotted line, a e, will not always comprehend the whole of the parapet, if the height, a b, of the demirevetment is less than about 20 feet.

So much having been said to give a general notion of the principles, according to which this part of our subject may be considered, I shall now state the rule, laid down by Vauban, for partial or demirevetments.

He made, in all cases, the dimensions of the base of his demirevetments, and of their counterforts, equal to those of a full revetment, calculated for a profile of the same relief or total height of scarp; besides which, in partial or demirevetments, he reduced the intervals between his counterforts to 15 feet, measuring from center to center, whilst in his full revetments, he always made these intervals equal to 18 feet, excepting under peculiarly unfavourable circumstances.

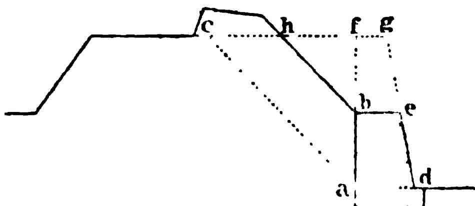
For example, if we suppose, that there are two profiles, each 40 feet high, exclusive of the parapet, and that the scarp of the former is fully reveted; but that, in the latter, one half only of the scarp is reveted: then, by referring to Vauban's general profile, as contained in the first table, it appears, that the thickness at top of the full revetment, proper for that height, is 5 feet 4 inches; the thickness at bottom being 13 feet 4 inches. And the dimensions of the counterfort, given for that height, in the same table, are 10 feet long, 6 feet wide at the root, and 4 feet wide at the tail. This being ascertained, it follows, therefore, in conformity with the rule, which has just been stated, that the demirevetment of 20 feet in height, under the circumstances above supposed, ought to be made 13 feet 4 inches thick at bottom, in consequence of which, its thickness at top, the slope being one fifth, will of course be 9 feet 4 inches; and it must be backed by counterforts of the above-named dimensions.

Hence it appears, that Vauban's demirevetments, or partial revetments, form an exact section of the lower part of one of his full revetments, in profiles of the same relief.

Draw, for example, the profile of a demirevetment, a b e d, having a slope of one fifth, over which, the upper part of the scarp,

exclusive of the parapet, is represented by b h; make the berm equal to the thickness at top of the masonry; and let the dotted oblique line, a c, mark the extent of the pressure of earth, in the usual manner.

This being done, produce, upwards, the back and front of the demirevetment, as far as the points, f and g, where they meet the level of the base of the parapet, also produced; and dot the whole of your produced lines.



Then, if we suppose the total height of scarp of our profile to be 40 feet, exclusive of the parapet, and that the demirevetment, a b, is 20 feet high: the figure, a f g d, will represent a full revetment calculated for a profile of the same total relief, as that of our present section. The thickness at bottom, a d, both in the full revetment and demirevetment, will be 18 feet 4 inches; but whilst the thickness at top, f g, of the former, is 5 feet 4 inches, the thickness at top, b e, of the latter, will, by reason of the slope, be increased to 9 feet 4 inches. And the demirevetment will evidently, as before stated, form an exact section of the lower half of the full revetment. In like manner, the counterfort of the demirevetment, a b e d, if introduced, ought to form an exact section of the lower half of the counterfort of the full revetment, a f g d.*

* In this manner were regulated the dimensions of the partial revetments and of their counterforts, given in Plate 2d, which are made to agree with Vauban's rule, as stated in the text, but with this difference, that a small addition has been made to their thickness, on account of the difference of slope, which is there reduced to one sixth.

According to the principle, before assumed, the pressure of earth on the demirevetment, is represented by the figure, a b h c, added to the parapet; whilst the pressure on the full revetment is represented by the triangle, a f c, added to the parapet.

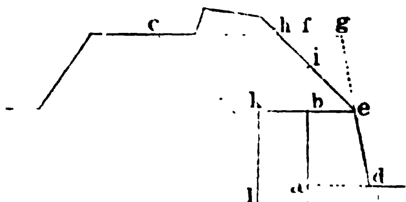
Using the above stated dimensions, and calculating in the manner followed in constructing the second table, it will be found, that whilst the masonry in the full revetment is to the pressure as 52·23 to 100,* the masonry in the demirevetment will be to the pressure acting upon it, as 40·85 to 100 nearly, the counterforts in both cases being of course included, and those of the full revetment being supposed to be built at intervals of 18 feet, whilst the others are supposed to be placed at intervals of 15 feet apart, from center to center.

The authors, who have written upon Vauban's general profile, have made a great omission, in neglecting to say, whether he considered a berm of a certain breadth, as an essential accessary to the strength of his partial revetments; nor does there appear to be sufficient information to enable us to form a decided opinion, as to his probable intentions on this head. It may, however, be observed, that unless a respectable berm is introduced in such cases, the rule laid down by Vauban, as above stated, does not seem by any means calculated to yield a sufficient strength of masonry, in proportion to the pressure of earth, which may be supposed to act upon partial or demi-revetments.

To exemplify this remark, construct a figure similar to your last, in every other respect, but without any berm; marking it with the same letters in all the corresponding points, and adding the letter,

* This proportion differs from that given in the second table, for a full revetment 40 feet high, because, in our present profile, the small exterior revetment of the parapet is suppressed; and the interval between the counterforts is supposed to be 18 feet, instead of the mean interval of 16½ feet, which was assumed in constructing that table.

i, to denote the point, where the earthen scarp is intersected by the back of the demirevetment, produced upwards.



Add also a counterfort, a b k l, to your demirevetment.

It will then appear, that the pressure of earth, acting upon the full revetment, will be as the triangle, a f c, added to the parapet, whilst the pressure upon the demirevetment will be as the irregular figure, a b e h c, added to the parapet. But whether as examined by the eye, or as more accurately ascertained by calculation, it will be found, that in most cases, which are likely to occur in practice, the area of the figure, a b e h c, will be so very nearly equal to that of the triangle, a f c, that the pressure upon the two revetments may be assumed, as being very nearly equal.

If, however, instead of estimating the pressure on the demirevetment, a b e d, by the figure, a b e h c, the portion, b i e, of the said figure is deducted, because this portion may be supposed, by resting perpendicularly on the top of the demirevetment, to tend rather to give stability to it, than otherwise; still there will remain the figure, a i h c, which is not, in any considerable degree, smaller than the triangle, a f c, that acts upon the full revetment. It would therefore appear, even under this last view of the subject, by no means prudent, to make the strength of the demirevetment much less than that of the full revetment; and this object evidently cannot be obtained by the above rule of Vauban: for if the pressure on both were allowed to be equal, it will be found by calculation, that the demirevetment ought to be no less than 13 feet 10 inches thick at top, and 17 feet 10 inches thick at bottom * (exclusive of counterforts), in order to give it the required

* These dimensions are found, by means of the formula, afterwards given, as the solution of question 6th, of the note to page 532.

strength; a profile, which in quantity of masonry would exceed one of Vauban's profiles of the same description and height, by almost one half, the latter being only 9 feet 4 inches thick at top, and 15 feet 4 inches thick at bottom, as was before stated.

With respect to the counterfort of a demirevetment, constructed according to our last figure, the weight of earth resting perpendicularly upon it, which would be represented by a trapezoid or irregular figure, whereof k b is the base, may be considered to add greatly to its stability, and to give it a power of strengthening the demirevetment, much greater than its actual mass of masonry could do, if it were not thus loaded.

Upon the whole, it may be concluded, that as far as regards full revetments, or scarp revetments carried up nearly to the level of the base of the parapet, Vauban's rules, or those which may be drawn from his practice, may be followed with perfect safety;*

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* There is one rule, laid down by Vauban, in respect to scarp revetments, which I have omitted in the text, it being entirely inapplicable to any well regulated profile. He recommends, in works, having cavaliers constructed in rear of them, whenever the distance between the foot of the cavalier and the parapet of the exterior work is less than 18 or 20 feet, that the thickness of the scarp revetment of the latter shall be increased beyond the usual proportion, by one tenth part of the total command of the cavalier; and that the counterforts shall also be increased in strength, by making them of the dimensions proper for those of a full revetment, equal in height to the given scarp revetment, added to one half of the command of the cavalier.

Thus, for example, if we suppose any work to have a full scarp revetment 25 feet high, with a cavalier in rear of it, having a command of 20 feet over the work itself: then to 5 feet 4 inches, the usual thickness of Vauban's revetments at top, add 2 feet (which is one tenth part of 20, the command of the cavalier), and the sum, 7 feet 4 inches, will show the proper thickness at top for the scarp revetment. With respect to the required counterfort of the supposed work; to 25 feet, the height of the scarp revetment, add 10 feet, which is one half of the given command of the cavalier, and the sum will be 35 feet. Then by referring to Vauban's general pro-

and the same remark may be made with respect to gorge or counterscarp revetments; in which, by an application of similar principles, there can be no risk of failure.

The only thing, that appears doubtful, is the last branch of this subject, which we have considered, namely the proper thickness for demirevetments or partial revetments, in profiles of a respectable relief. The rules laid down by Vauban on this head have not been sufficiently supported by experience, to enable us to adopt them without hesitation, for we have very few instances of this kind of profile having yet been used. And in cases, where we have authentic descriptions of the dimensions of partial revetments, that have actually been executed, there has not only always been a broad berm, which of course makes a difference in the pressure, but the heights both of the revetment and of the earthen

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file, you will find, that counterforts 9 feet long, 5 feet 6 inches wide at the root, and 3 feet 8 inches wide at the tail, are proper for the above height; and such are the dimensions, according to that Engineer, which ought to be given to the counterforts of the supposed scarp revetment (although only 25 feet high), on account of its having a cavalier of 20 feet total command in rear of it.

To explain my objections to the above rule of Vauban, I shall remark, that in a well-regulated profile, a free space of at least 20 feet should always be left between the base of the parapet of any work having a cavalier in rear of it, and the foot of the cavalier; otherwise the terrepleins of the work will be too narrow for the service of artillery. But at the above distance, supposing the work in question to have a parapet of the proper thickness, there must necessarily be an interval of at least 33 feet, between the foot of the cavalier and the back of the scarp revetment of the work in front of it, at which interval, it will be evident, that the mass of the former work will be too far removed, to add to the pressure of earth tending to overset the latter, even if the said revetment should be of a very respectable height. If the cavalier itself is also reveted, it should be removed still further to the rear, than we have just supposed, for reasons stated in Chapter XVII, page 342: so that upon the whole, there can scarcely be any case, in which the thickness of the scarp revetment of a work ought to be increased, on account of its having a cavalier in rear of it.

scarp above it, have usually been so insignificant, as not to afford, upon the whole, sufficient data, for judging with confidence, upon the strength of bolder profiles of the same description.*

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* In Belidor's "Science des Ingenieurs," Book Sixth, in which he gives the rules laid down for the construction of New Brisach, it is directed, that the ravelins shall have a scarp revetment of 17 feet in height, over which a berm is to be left, 10 feet broad; and then an earthen scarp is to be raised 8 feet 6 inches high, exclusive of the parapet. The revetment is to be 5 feet 4 inches thick, at the height of 14 feet from the ground, with a slope of one sixth from thence downwards. The remaining part of the revetment, near the top, is to be built perpendicularly, 2 feet 8 inches thick, and 3 feet high. The counterforts to be 8 feet long, 5 feet wide at the root, and 3 feet wide at the tail. Belidor states, that the rules, given by him in that book, as an exemplification of the system, according to which the details of the construction of an entirely new fortress may be regulated, are not, in all cases, an exact copy of those, which were actually used on that occasion, but that he has generally followed the same dimensions. If this is supposed to hold good in respect to the ravelins, which have been described, it would appear that, with the exception of the counterforts, the rest of the masonry of the profile is not increased in proportion to the height of earthen scarp above it: on the contrary, the strength of the scarp revetment is less than what ought to have been given to a full revetment, 17 feet high. If so, it would seem, that when a good berm was left, Vauban, by whom the above fortress was constructed, did not think it necessary to increase the thickness of partial or demirevetments; but as this is only one solitary case, his intentions cannot from thence be fairly estimated.

In Portsea Works, there is a berm of about 10 feet wide all round, the height of the earthen part of the scarp above that level (not including the parapet) being generally about 8 feet. The partial revetments are in some parts 8 feet thick at the top, with a slope of one sixth. Their height varies much, according to the nature of the soil, being in some parts no less than 38 feet, but a very great portion of the masonry is every-where buried below the level of the ditch, it having been judged necessary, by the engineer, who had charge of the work, to go down, until a peculiar stratum of clay, that he considered good for the foundations, was found. In some parts, the thickness at top of the partial revetment is only 6 feet, but the average thickness in most places is 7 feet 6 inches. The counterforts are 8 feet long, 6 feet 8 inches wide at the root, and 5 feet wide at the tail; and are placed at central intervals of 18 feet apart.

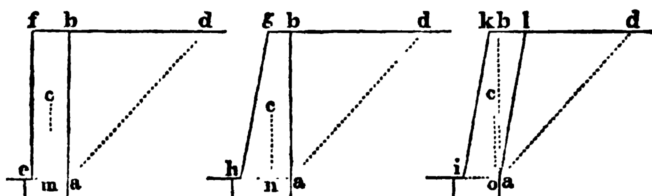
Having now sufficiently enlarged upon the general profile of Vauban, which it was of importance to illustrate, as it has hitherto been almost implicitly followed by every succeeding engineer, I shall next proceed to explain another form, that may be given to the profile of retaining walls, and which is peculiarly applicable to military works, but has not yet, to my knowledge, been used in the scarp or counterscarp revetments of any fortress, although, upon due consideration, it may perhaps appear preferable to the former.

The method, now alluded to, consists in constructing the wall in such a manner, that whilst the front of it has a certain exterior slope like a common revetment, the rear of it shall not be built perpendicularly, in the usual manner, but shall also have a slope, parallel and equal to the former, or nearly so. When this profile is used, the back of the masonry overhangs or projects beyond the base of it, and appears as it were to lean against the mass of earth, that it is intended to retain; from which circumstance, revetments, so constructed, are called LEANING REVETMENTS.

The overhanging slope of a leaning revetment should never be so considerable, that if the counterforts and earth were removed, the wall would have any tendency to fall backwards. It may, however, without any inconveniency be made to differ in a small degree from the exterior or front slope; but generally speaking, it will be best to make these two slopes equal to each other, in which case the section of the masonry will be an oblique angled parallelogram; and this form, as being the most convenient for calculation, will be the only one noticed, in the succeeding parts of this chapter.

To exemplify the nature and strength of leaning revetments, as compared with others, draw three profiles of counterscarp revetments, of the same height but of different kinds, making the first rectangular, the second a common sloping revetment, and the third a parallelogrammatic leaning revetment; and let the mean thickness

of the sloping revetment, the thickness of the rectangular revetment, and the horizontal thickness of the leaning revetment, be equal to each other. From the back, a, of the base of each revetment, draw an oblique dotted line, sloping upwards and towards the rear, in the proportion of 1 to 1: from the center of gravity, c, of each profile, drop a dotted perpendicular to the base: from the back of the base of your leaning revetment, raise a dotted vertical line, a b, and letter the other points of your figures as follows.



Let us suppose, as before, the height of all your revetments to be 30 feet, and that the base and top of the first and third revetments are each 8 feet, which is equal to the mean thickness of the second revetment; and let us further suppose that the slopes of the second and third revetments are equal to one fifth of their height. Then the thickness at top, g b, of the second revetment, will be equal to 5 feet; its base, h a, will be 11 feet; and, b l, in the third profile, will be equal to 6 feet, which is one fifth of the supposed height.

Now, as the quantity of masonry in each revetment is equal, their strength, as opposed to a pressure of earth in rear of them, will be in proportion to their respective levers, e m, h n, and, i o; but on account of the first profile being rectangular, e m, will be equal to 4 feet, which is half the base, and by calculation, h n, will be found to be equal to 6·8125 feet, as in our former example, whilst i o will be equal to 7 feet. If we supposed the force of earth pressing upon each revetment to be equal, their comparative strengths would therefore be as the numbers 4, 6·8125, and 7; or on reducing these terms lower, as the num-

bers 1, 1·703125, and 1·75 : by which it would appear, that the leaning revetment is stronger by three fourths than the rectangular revetment, and that it is stronger by about one thirty-sixth part, than the common sloping revetment, they being all of the same height, and containing the same quantity of masonry.*

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* The following algebraical formulæ will be useful, in calculating the strength of masonry of various revetments, according to the hypothesis, stated in the text; it being understood, however, that the pressure of earth is not taken into consideration. When that is done, as is absolutely necessary, before the true comparative strength of any two profiles of fortification can be ascertained, a certain modification of the results, obtained by our present formulæ, must necessarily take place, as shall hereafter be explained; and consequently, these results are not conclusive, but each of them is merely to be considered as a step, towards the solution of a more complex and difficult question.

QUESTION I. Given the dimensions of any revetment, to find the length of lever, x, with which it opposes the pressure of earth; as also the stability of the masonry.

Case 1st. When the revetment is supposed to be rectangular, like that represented in our first figure, its height (a b) being equal to a, and its thickness (f b or e a) being equal to b.

SOLUTION. $x = \frac{b}{2} =$ e m in the figure: and the stability of the revetment, which is as the area of a b f e, multiplied into e m, will be $= ab \times \frac{b}{2} = \frac{ab^2}{2}$.

Case 2d. When the revetment is of the common sloping form, represented in our second figure, its height (a b) being equal to a; its thickness at top (g b) equal to b, and its slope being in the proportion of $\frac{1}{c}$ part of the height.

SOLUTION. $x = \frac{2ab+3b^2c}{3a+6bc} + \frac{2a}{3c} =$ h n in the figure, and the stability of the masonry, which is as the area of a b g h × h n, will be $= \left(\frac{a^2}{2c} + ab\right) \times \left(\frac{2ab+3b^2c}{3a+6bc} + \frac{2a}{3c}\right) = \frac{2a^3+6a^2bc+3ab^2c^2}{6c^2} = \frac{a^3}{3c^2} + \frac{a^2b}{c} + \frac{ab^2}{2}$.

Case 3d. When the revetment is a leaning parallelogrammatic one, as represented in the third figure, its perpendicular height (a b) being equal

But when the comparative pressure of earth is also taken into consideration, it will appear, that the quantity of earth which presses upon the back of the leaning revetment must necessarily

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to a, its horizontal thickness (k l or i a) being equal to b, and its slopes being in the proportion of $\frac{1}{c}$ part of the height.

SOLUTION. $x = \frac{a+bc}{2c} =$ i o, in the figure; and the stability of the masonry, which is as the area of a l k i × i o, will be $= ab \times \frac{a+bc}{2c}$ $\frac{a^2b+ab^2c}{2c} = \frac{a^2b}{2c} + \frac{ab^2}{2}$.

Case 4th. When the revetment is a countersloping one, as represented in the second figure of page 516, its height (D E) being equal to a; its thickness at top, (B E) equal to b, and its counterslope being in the proportion of $\frac{1}{c}$ part of the height.

SOLUTION. $x = \frac{ab+3b^2c}{3a+6bc} + \frac{a}{3c} =$ H D in the figure, and the stability of the masonry, which is as the area of A B E D × H D, will be $=$ $\left(\frac{a^2}{2c} + ab\right) \times \left(\frac{ab+3b^2c}{3a+6bc} + \frac{a}{3c}\right) = \frac{a^3+3a^2bc+3ab^2c^2}{6c^2} = \frac{a^3}{6c^2} + \frac{a^2b}{2c} + \frac{ab^2}{2}$.

QUESTION II. Given the height, a, and thickness, b, of a rectangular revetment; to find the thickness, x, of a second rectangular revetment, of a given height, d, and equal to the former in strength.

SOLUTION. $x = \sqrt{\left(\frac{ab^2}{d}\right)} = b\sqrt{\left(\frac{a}{d}\right)}$.

QUESTION III. Given the height, a, and thickness, b, of a rectangular revetment; to find the thickness at top, x, of a sloping revetment, of a given height, d, and having a slope of $\frac{1}{c}$, and equal to the former in strength.

SOLUTION. $= \sqrt{\left(\frac{ab^2}{d}\right) + \frac{d^2}{3c^2}} - \frac{d}{c}$.

QUESTION IV. Given the height, a, and thickness, b, of a rectangular revetment; to find the thickness at top, x, of a leaning revetment, of a given height, d, and having a slope of $\frac{1}{c}$, and equal to the former in strength.

be somewhat less, than that which acts upon either of the two other profiles; and therefore the above ratio must be modified, in a certain degree, in order to obtain the true proportions.

SOLUTION. $x = \sqrt{\left(\frac{ab^2}{d}\right) + \frac{d^2}{4c^2}} - \frac{d}{2c}$.

QUESTION V. Given the height, a, the thickness at top, b, and the slope, $\frac{1}{c}$, of a sloping revetment; to find the thickness, x, of a rectangular revetment, of a given height, d, and equal to the former in strength.

SOLUTION. $x = \sqrt{\frac{a}{d}\left(b^2 + \frac{2ab}{c} + \frac{2a^2}{3c^2}\right)}$.

QUESTION VI. Given the height, a, the thickness at top, b, and the slope, $\frac{1}{c}$, of a sloping revetment; to find x, the thickness at top of a second sloping revetment, of a given height, d, and having a slope of $\frac{1}{e}$, and equal to the former in strength.

SOLUTION. $x = \sqrt{\frac{a}{d}\left(b^2 + \frac{2ab}{c} + \frac{2a^2}{3c^2}\right) + \frac{d^2}{3e^2}} - \frac{d}{e}$.

QUESTION VII. Given the height, a, the thickness at top, b, and the slope, $\frac{1}{c}$, of a sloping revetment, to find the thickness, x, of a leaning revetment, of a given height, d, and having slopes of $\frac{1}{e}$, and equal to the former in strength.

SOLUTION. $x = \sqrt{\frac{a}{d}\left(b^2 + \frac{2ab}{c} + \frac{2a^2}{3c^2}\right) + \frac{d^2}{4e^2}} - \frac{d}{2e}$.

QUESTION VIII. Given the height, a, the thickness, b, and the slopes, $\frac{1}{c}$, of a leaning revetment; to find the thickness, x, of a rectangular revetment, of a given height, d, and equal to the former in strength.

SOLUTION. $x = \sqrt{\frac{a}{d}\left(b^2 + \frac{ab}{c}\right)}$.

QUESTION IX. Given the height, a, the thickness, b, and the slopes, $\frac{1}{c}$, of a leaning revetment; to find the thickness at top, x, of a sloping

To explain this observation, let us suppose, according to the hypothesis used in our former calculations; that the comparative pressure of earth upon the back of the revetment, in each of our

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revetment of a given height, d, and having a slope of $\frac{1}{e}$, and equal to the former in strength.

SOLUTION. $x = \sqrt{\frac{a}{d}\left(b^2 + \frac{ab}{c}\right) + \frac{d^2}{3e^2}} - \frac{d}{e}$.

QUESTION X. Given the height, a, the thickness, b, and the slopes, $\frac{1}{c}$, of a leaning revetment, to find the thickness, x, of a second leaning revetment, of a given height, d, and having slopes of $\frac{1}{e}$, and equal to the former in strength.

SOLUTION. $x = \sqrt{\frac{a}{d}\left(b^2 + \frac{ab}{c}\right) + \frac{d^2}{4e^2}} - \frac{d}{2e}$.

QUESTION XI. Given the dimensions of a revetment of a given description, that is to say, either rectangular, sloping, or leaning; to find the thickness at top of a second revetment, also of a given description and height, and of a given slope, if sloping or leaning; and which shall be stronger or weaker than the former by $\frac{1}{n}$th part.

GENERAL RULE FOR THE SOLUTION. From amongst the foregoing questions, select that, whose conditions agree most nearly with those of your present case; and multiply that part of the solution of the said question, which is within the vinculum under the radical sign, by $\frac{n+1}{n}$, if you desire your proposed revetment to be stronger than your given one, but multiply by $\frac{n-1}{n}$, if you desire it to be weaker; leaving all the other terms of the solution unaltered. This will give you the answer to your new question.

For example: supposing that the height, a, the thickness at top, b, and the slope, $\frac{1}{c}$, of a sloping revetment are given, and that it is required to find the thickness, x, of a leaning revetment, of a given height, d, and having slopes of $\frac{1}{e}$, and which shall be stronger than the former

profiles, is as the triangles, a b d, a b d, and a l d, bounded in rear by the oblique dotted lines, sloping in the proportion of 1 to 1. Then the lines, marked, b d, and a b, will be equal in all our figures, and from the nature of the overhanging slope in the third profile, b l, being equal to one fifth part of b d; the line, l d, will be equal to four fifths of b d. Now on comparing the triangle, a l d, with the triangles marked, a b d, as their altitudes are equal, the area of the former will be in proportion to the line, l d, whilst the area of each of the others will be in proportion to the line, b d. The area of the triangle, a l d, which represents the pressure of earth upon the leaning revetment, will therefore be equal to four fifths only of the triangle, a b d, which represents the pressure, acting upon the two other revetments, shown in our first and second figures; or in other words, the pressure of earth, acting upon the rectangular and upon the common sloping revetment, is greater by one fourth part, than that which acts upon the parallelogrammatic leaning revetment.

The dimensions of a counterscarp revetment, so nicely proportioned as to be exactly in equilibrium with the pressure of earth acting upon it, have not yet, to my knowledge, been ascertained by experiment; and therefore the value of the additional strength, which our leaning revetment must possess, as compared with the others, by reason of the diminution of pressure, occasioned by its

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by $\frac{1}{n}$th part: then, on referring to the foregoing questions, it will be found that the above conditions agree most nearly with those of Question VII, the solution of which is $\sqrt{\frac{a}{d}\left(b^2 + \frac{2ab}{c} + \frac{2a^2}{3c^2}\right) + \frac{d^2}{4e^2}} - \frac{d}{2e}$: and consequently on multiplying that part of the said solution, which is within the vinculum, by $\frac{n+1}{n}$, as directed, there will result for the answer of your present question, $x = \sqrt{\frac{a}{d} \times \frac{n+1}{n}\left(b^2 + \frac{2ab}{c} + \frac{2a^2}{3c^2}\right) + \frac{d^2}{4e^2}} - \frac{d}{2e}$.

overhanging slope, cannot be reduced to any precise ratio; as might be done, if the supposed experiment were carried on, in a satisfactory manner. For example if we imagine, that it had been practically ascertained, that a rectangular revetment, of the dimensions represented in our first figure, were in exact equilibrium with the supposed pressure of earth acting upon it, then as the said pressure has just been shown to be greater by one fourth, than that which acts upon the leaning revetment of our third figure, it would therefore follow, that to the number 1·75, before found, which represented the actual strength of masonry of our third profile, one fourth of itself should be added; and the sum 2·1875, would then show the comparative strength of that profile, as a retaining wall, under the circumstances supposed; whilst the comparative strength of the rectangular revetment, and that of the common sloping revetment, would still remain as the numbers 1, and 1·703125.*

Upon the whole, therefore, it may appear, that there are sufficient grounds for concluding, that a leaning revetment must be stronger, in a certain degree, than any of the other profiles of revetments, which have been described; but whether it exceeds them in strength, in the proportions, which we have just found by calculation, according to a certain stated hypothesis, must remain doubtful, until the matter is put to the test of actual experiment.

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* On considering the mode, in which we have just calculated the comparative strength of our three profiles, it will appear evident, that if the soil, which was to be retained, had been either of a more or less tenacious quality, than what we have above supposed; then the superiority, in point of comparative strength, which the leaning revetment, represented in our third figure, must, in all cases, possess over the others, would have been increased or diminished, to a certain degree, so as to differ more or less from the ratios, which were found by our former supposition.

CHAP. XXV.

THE SAME SUBJECT CONTINUED. — OBSERVATIONS ON THE UNSATISFACTORY AND ERRONEOUS NATURE OF THE COMMON THEORIES OF REVETMENTS. — NEW PRINCIPLES LAID DOWN.—ACCOUNT OF EXPERIMENTS TRIED FOR THE PURPOSE OF ASCERTAINING THE ACTION OF LOOSE EARTH UPON REVETMENTS.—GENERAL RULES DEDUCED FROM THE ABOVE.

The investigation of the dimensions proper for revetments of various descriptions, which has been partly treated of in the foregoing chapter, is one of the most important objects, that can engage the attention of the practical Engineer; for if the masonry of any revetment should prove defective, the whole of the expense, laid out in the construction of the work, will be thrown away; and, on the other hand, even an excess of strength is to be reprobated, as leading to an useless waste of masonry and materials. And in those cases, in which revetments, properly so styled, are used; as for example, in the scarps and counterscarps of fortified places, and in the facing of docks, wharfs, &c. the reveted works, whether civil or military, are always of great public importance, and are attended with a vast expense, even if planned according to the wisest principles; so that a defect in the profile of a revetment must generally prove far more ruinous, than any common error, which is likely to occur in other branches of practical mechanics.

Notwithstanding these weighty considerations, there is, however, no branch of useful study, which appears to me to have been handled in so very unsatisfactory a manner, as that of which we are now treating. It is true, that a great number of writers have attempted to illustrate the theory of revetments by mathematical calculations, but they have all neglected to establish their principles by previous experiments. The rules, given by them, must therefore

be looked upon as mere speculations, on which no reliance could be placed in practice; for the various points to be considered are certainly of by far too abstruse a nature, to be capable of being ascertained by reasoning alone. But independent of the difficulties and uncertainty, attending the subject in itself, there is another consideration, which has rendered me the more averse, from giving confidence to any of these writers, however learned or ingenious. Even the preliminary hypothesis, usually laid down by them, as to the pressure of earth upon revetments, seems to me to be erroneous; and if this opinion should prove to be well founded, all the theories, which have hitherto been published upon the subject, must necessarily fall to the ground.

But if we set aside the doctrines of speculative writers, we have nothing conclusive or satisfactory, at least as far as regards military works, but the rules given by Vauban: and upon these it must be remarked, that they apply to one particular kind of profile only. In other cases, before stated, in which we are not aware, that Vauban proved his rules by actual practice, it would not, by any means, be equally safe to trust to them.

Upon the whole, therefore, the only positive knowledge, that we can be said to possess upon this important subject, is as follows. If, in planning a fortress, we should think proper to adopt full revetments, like those of Vauban, we may with confidence use the dimensions, prescribed in his general profile, as having been proved by ample experience to be sufficiently strong; but still a doubt may reasonably remain in our minds, whether these dimensions may not be greater than necessity requires. But if we should prefer partial revetments, either with narrow berms or without any; which, for reasons explained in former parts of this work, are much more suitable for the profiles of a fortress, than full revetments; then we have only the theories, or rather conjectures, of speculative writers to guide us, in regulating the dimensions of our masonry, and it must certainly be allowed, that nothing can be more unsatis-

factory, as I before stated, than this view of the subject. In the course of the extensive public works, which have been carried on at various times, in different parts of the world, fractures must occasionally have taken place in the masonry, owing to a want of proper strength to resist the pressure of earth. If these had been carefully recorded, much insight into this subject would have been obtained; but such incidents are usually kept in the back ground, as much as possible; so that it would scarcely be practicable to collect a sufficient number to answer the purpose in view. As the matter is of great importance, a series of experiments, calculated to ascertain the greatest pressure of earth, that walls of a certain quantity of masonry can support, under given circumstances, before they will break down, may therefore be considered, not merely as the only rational means of attaining any precise knowledge on the subject, but also as a desirable object in a public point of view.

Having asserted, that I consider the theories of those writers who have treated this subject mathematically, as being of a very unsatisfactory nature; I shall next proceed to explain the grounds, upon which I have formed this opinion.

One principle, in which they almost all agree, is that the strength of revetments, in general, as opposed to a power acting upon the back of them, is in proportion to their masses, multiplied into their respective levers, which are found, in the manner explained in the preceding chapter, by dropping a vertical line from the center of gravity to the base of each revetment.

It is also generally allowed, that if two revetments are built of different materials, but of the same profile, that which is composed of the lightest substance, will be the weakest; and, for this reason, it has been recommended, that a brick wall should be made rather thicker than a stone wall, exposed to the same pressure of earth; because the stone, which is generally used in building, in this country, is heavier than brick.

So far the truth of the rules, usually given in books, may be

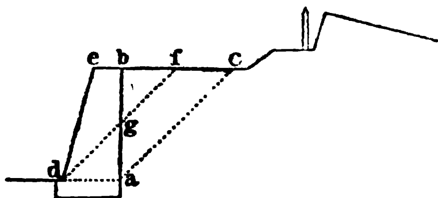
readily allowed; as they either seem founded upon very obvious principles, or are such as agree with the daily experience of Engineers, and others employed in public works. With regard to the strength of masonry, I should not therefore be inclined to make any difficulty; but when the nature of the pressure of earth comes to be considered, the case is widely different.

In this part of their subject, the writers on the theory are agreed in one point only, namely, in allowing, that the weight of earth, pressing upon the back of any revetment, and tending to overset it, is in proportion to a triangle, or other figure, which may be found in the manner explained in the preceding chapter, by drawing a line, from the rear of the base of the revetment, to the surface of the earth behind it, sloping in a certain proportion, as for example, at an angle of 45 degrees. This is precisely the hypothesis, before alluded to, which appears to me to be founded in error; and therefore, in explaining and reasoning upon the said hypothesis, which I have hitherto done, in treating of the present part of my subject, notwithstanding my belief of its inaccuracy, I had solely in view the full information of my readers, in order that they might not remain ignorant of the opinions held by former writers.*

* It was stated, that the various speculative writers upon this subject all concur, in assuming one common hypothesis, as to the quantity of earth, which presses upon the back of a revetment, with a tendency to overset it. But when they treat of the modification, which must necessarily take place in the actual force, exerted by the above mass of earth, on account of various circumstances, such as the position of its center of gravity, &c. &c., in consequence of which, the same actual weight or mass of earth may be supposed to be much more oppressive to a revetment, in some cases, than in others; then the writers, alluded to, are all at variance with each other, all of them having different theories of their own, which they generally hold out with considerable confidence, for the guidance of the practical Engineer; and considering the acknowledged talents of those, who have investigated the pressure of earth, this discordancy in the inferences, which they have drawn from one common hypothesis, may be deemed a proof of the

Had these opinions been less generally received, I should have preferred passing them over in total silence, for their fallacy may be proved in a manner sufficiently obvious, even by reasoning alone; and the strong objections against them, which first occurred to me, in reflecting upon the subject, have lately been corroborated by experiments of a very simple and yet convincing nature, that shall hereafter be stated, and of the accuracy of which any person may easily satisfy himself at a moderate expense.

To explain these observations; draw a counterscarp revetment, a b e d, with an oblique dotted line, a c, to represent the extent of the pressure of earth, in the usual manner, before exemplified; and from the front of the base of the revetment, draw a second oblique dotted line, d f, parallel to the former, intersecting the back of the revetment, in the point, g. Then I say, that the triangle, a b c,



obscurity of the subject; for in matters capable of demonstration by geometrical reasoning, the results are always conclusive and convincing. This is the case in Pure Mathematics, in which are investigated the nature of lines, angles, geometrical figures, numbers, and other things, that may be considered intellectually, without any reference to the properties of matter. But in Mixed Mathematics, in which the consideration of material substances is also introduced, certain data must always be assumed, and some hypothesis must consequently be laid down, as to the properties of the substances to be treated of, before any mathematical reasoning can be applied to the subject; and these data are not, like the axioms of geometry, of a self-evident nature, or capable of demonstration. On the contrary, they are usually involved in great obscurity and uncertainty, if considered intellectually: and it is, therefore, by means of numerous experiments alone, conducted under many and various contingent circumstances, that a just or useful hypothesis, of the nature alluded to, can be formed; after which, Mathematics may be applied, with the greatest advantage, to the determination of new cases, but not before.

although usually so considered, is not a true representation of the quantity of earth, which presses on the revetment, a b e d, in such a manner as to tend to overset it, on the pivot or fulcrum, d.

The line, a c, in our figure, represents the natural slope, at which the earth of the counterscarp would be able to stand of itself, without the assistance of masonry. Consequently, as the line, d f, which is parallel to it, has exactly the same slope, it must also be allowed, that if there were no revetment, the earth would be able to stand equally well, according to the last mentioned line, as according to the former. If we therefore suppose the upper portion, g b e d, of our revetment to be cut entirely off, as also the upper portion of earth, g b f, there will remain, according to the common hypothesis, a mass of earth, a g f c, pressing upon the back of the triangular revetment, a g d, and tending to overset it, by throwing it over upon the pivot, d.

Now, by supposition, the line, d f, represents the natural slope, at which the earth of the counterscarp will stand, without being supported. If therefore, the triangle, a g d, were composed of earth of the same quality, instead of forming part of a revetment; it must be evident, that the whole body of earth, contained in the counterscarp, of which, d f, represents the exterior surface, would remain in a state of rest; nor can it be pretended, under this supposition, that the portion of earth, a g f c, would have the least tendency to overset the triangular portion of earth, a g d.

But if the earth, contained in a g f c, has no power or tendency to overset the triangle, a g d, in case the said triangle were also composed of common earth; it may be considered reasonable to believe, that it must have much less power, and by no means a greater tendency, to overset the same triangular mass, if instead of being formed of earth, it were converted into masonry, which is a harder and heavier substance, adhering together in a compact manner, without any loose particles. And if such is the case; namely, if the portion of earth, a g f c, has no tendency whatever

to overset the revetment, it must necessarily be allowed, that instead of measuring the pressure of earth, which acts with that tendency, upon the masonry of our profile, by the triangle, a b c; it ought more properly to be estimated by the smaller triangle, g b f, which does not press upon the whole mass of the revetment, d e b a, but upon that portion of it only, which is represented by the figure, d e b g.

It is to be observed however, that although the portion of earth, a g f c, has thus been proved to possess no tendency whatever to overset the revetment, yet the whole of it must necessarily press upon the lower part of the masonry, in a certain manner; for it will be evident, that if the wall were entirely removed, the said mass of earth could not remain perpendicular in front, in the form, a g, but would fall forwards. Now, any lateral pressure, which is incapable of oversetting a body, has a tendency to make it slide, if circumstances will permit, and such, therefore, would be the tendency of the action of the earth, a g f c, upon the revetment; but from the nature of earth and of masonry, and from the stability, which the latter derives on account of its base being buried some feet in the ground, it is impossible that this sliding motion can be carried into effect; and consequently, as it can neither cause the revetment to overset, nor to slide, the tendency of the pressure of the portion of earth, a g f c, which acts upon the lower part of it, is to force it downwards, but in an oblique direction, upon its base. There, however, it is resisted by a mass of solid ground, which, if the foundation is good, it will be unable either to remove or to penetrate; and therefore, all things considered, it may be allowed, that the actual tendency of the portion of earth, a g f c, is to steady the revetment, by pressing it firmly down upon its base, with a considerable weight, which must be overcome by some superior power, before the wall can possibly overset.

From the above considerations, it will therefore appear, that if any mass of earth, such as the triangle, a b c, which is supported

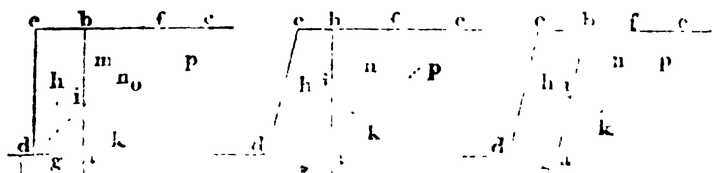
by a revetment or retaining wall, a b c d, is divided into two portions, by an oblique line, d f, drawn from the front of the base of the masonry, backwards, at the same slope, at which the earth would stand of itself, without any revetment; it is only THE UPPER PORTION, g b f, of the supported mass, which can have the least tendency to overset the revetment; for THE LOWER PORTION, a g f c, will in all cases add stability to it. The latter shall therefore, for the sake of precision, be styled THE STABILITATING PORTION OF THE SUPPORTED MASS OF EARTH: the line, d f, which divides it from the upper portion of the said mass, shall be called THE LINE OF SEPARATION, and the line, a c, which bounds the whole, shall be called the BOUNDARY LINE.

Having so far explained the leading principle, in which I differ from former writers, I shall here remark, that if what I have styled the upper portion of the supported earth, had no other tendency or action whatever, than to throw down the revetment, by moving it upon the pivot, d, it would in all probability not be a difficult task to form a correct theory of revetments upon the new hypothesis, which I have just laid down; but there are further considerations to be taken into account, which render the investigation of the pressure of earth of so very complicated a nature, that it seems to me doubtful, whether it will be possible to reduce it to a matter of calculation, at least by any simple process, likely to be practically useful.*

* For example, draw three figures of counterscarp revetments, all of equal height, the first rectangular, the second sloping, the third leaning. Mark each revetment by the letters, a b c d, and from the center of gravity, h, of the masonry, drop a vertical line, h g, to the base. Mark the line of separation, in each figure, by the letters, d i f, and the boundary line by the letters, a c, both of which are supposed to be drawn at an angle of 45 degrees. In the first figure, let the point, m, represent the center of gravity of the upper portion, i b f, of the supported earth, and let o represent the

I allude to the property, which loose earth possesses, of acting, not in one direction merely, but in a great variety of different directions, until it finds its natural slope. For example, if we suppose the point, o, in the annexed figure (*see page* 548), to represent any particle of earth of the upper portion, g b f, it will be evident, that if it were not supported by the mass of earth beneath it, it would fall down vertically, in the direction, o m. If we suppose it to be supported in the direction, m, and towards n, but not further

center of gravity of the stabilitating portion, a i f c; and from these points, draw perpendiculars, m n, o n, to the line of separation, d f. Lastly, in every figure, from the point, b, draw b n, perpendicular to i f, and from the points, f and i, draw f p, and i k, perpendicular to a c.



Then, if we could suppose the upper portion, i b f, of the supported earth, in each figure, to act solely with a tendency to overthrow the revetment: that is to say, that no part of its pressure whatever should be exerted in any direction falling within the base, a d, of the masonry; it would follow, that every particle of the supported earth lying above the line, d f, would tend to overset or weaken, and that every particle of the same mass, lying below the line, d f, would tend to stabilitate or strengthen the revetment; whilst those particles, the center of which coincided with the line, i f, would, as it were, remain neutral. Consequently, the portions, i b f, and a i f c, in each figure, might not unreasonably be compared to the two counteracting weights in a pair of scales, of which the fulcrum would always correspond with some part of the line of separation, i f; so that the same doctrine might be supposed to hold good in both cases: that is to say, the actual force, exerted by the upper portion of earth to overset the revetment, upon the pivot, d, might be supposed to be in proportion to its mass or area, i b f, multiplied into the lever (m n) which represents the perpendicular distance of its center of gravity (m) from the line of separation, i f; and, in like manner, the actual force, exerted by the stabilitating mass to strengthen the revetment, by pressing upon the base, a d, might be supposed to be in proportion to the mass or area, a i f c, of the

than n, it would then fall or slide down, in the direction, o n. Again, if we suppose it to be supported in every point from m, towards p, but not further than the direction, p, then it would move in the direction, o p; but if o p, is nearly parallel to f d, the natural slope at which the earth will stand of itself, it will be evident, that the particle, o, can have no tendency whatever to move in the direction, o q, or in any other direction higher than the point, p.

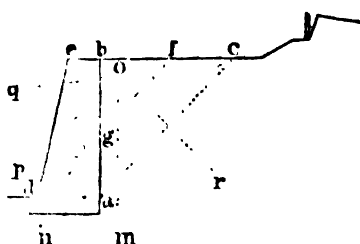
said portion, multiplied into the lever (o n) which represents the perpendicular distance of its center of gravity (o) from the line of separation, i f: and, at the same time, according to the common doctrine of former writers, the power of resistance or stability of the masonry, against any force, tending to overset it on the pivot, d, might be supposed to be in proportion to its mass or area, a b e d, multiplied into the lever, d g; and if it is supposed to be built of brickwork, it will have the same specific gravity as common earth nearly. Consequently, if it were required to find the thickness at bottom, a d, of a brick wall, so nicely proportioned, that the stability of the masonry, assisted by the force of the stabilitating portion of the supported earth, should be in exact equilibrium with the oversetting force of the upper portion of the supported earth, the statement of our question in the rectangular revetment, represented in the first figure, would be as follows.

Area a b e d × d g + area a i f c × o n = area i b f × m n. But from the construction of our figures, b n will, in all cases, be equal to n f, and f p, or i k, will be equal to p c; and from the properties of the center of gravity of bodies, the area of a i f c × o n, will be equal to the area of the two triangles (a k i + f p c) $\times \frac{2}{3}$ f p, added to the area of the rectangle k i f p $\times \frac{1}{2}$ f p: and the perpendicular distance of the center of gravity of the triangle, i b f, from the line of separation, i f, will always be equal to one third of the perpendicular, b n, although it may not always coincide with any part of the said perpendicular, as represented in our first figure. The former equation will, therefore, by substitution, assume the following form:

$$a\,b\,e\,d \times d\,g + (a\,k\,i + f\,p\,c) \times \frac{2\,f\,p}{3} + k\,i\,f\,p \times \frac{f\,p}{2} = i\,b\,f \times \frac{b\,n}{3}:$$

And this last general statement will hold good, in all our three figures, and it is more convenient than the former, because it does away the necessity

If the line, o r, is drawn in a contrary direction, so that the angle, m o r, shall be equal to the angle, m o p; the particle, o, will in like manner have a similar tendency to fall or move in any direction between m, and r, unless it is properly supported. But as its action



of finding the precise position of the points, m. and o. The same question shall next be treated algebraically.

QUESTION. Given the perpendicular height of any revetment, of a given description, that is to say, rectangular, sloping, or leaning, to find x, the thickness at bottom, which ought to be given to the wall, in order that the stability of the masonry, aided by the force of the stabilitating portion of the supported earth, shall be in equilibrium with the oversetting power of the upper portion of the supported earth; the specific gravity of the masonry and earth being supposed to be equal, and the latter being supposed capable of standing at an angle of 45 degrees.

CASE 1. When the revetment is rectangular, and its given height is supposed to be $= a$.

Under this supposition, by substituting n, as the value of the square root of 2, the stability of the masonry will be represented by $\frac{ax^2}{2}$; the force of the stabilitating portion of the supported earth will be represented by $\frac{ax^2}{2n} - \frac{x^3}{6n}$; and the force of the upper portion of the supported earth will be represented by $\frac{(a-x)^3}{6n}$. Consequently the statement of the question will be as follows.

$$\frac{ax^2}{2} + \frac{ax^2}{2n} - \frac{x^3}{6n} = \frac{(a-x)^3}{6n}.$$

SOLUTION. $x = \sqrt{\frac{a^2}{8} + \frac{a^2}{8n}} - \frac{a}{2n}.$

CASE 2. When the revetment is sloping; its given height being supposed to be $= a$, and its given slope $= \frac{1}{c}$.

In this case the value of the stability of the masonry will be $\frac{ax^2}{2} - \frac{a^3}{6c^2}$.

on that side of the vertical line, o m, can produce no effect whatever upon the revetment, we shall take no further notice of it.

Now it has been shewn, that the particle of earth, o, has a tendency to move, unless supported, in any given direction, between the points, m, and p; and consequently, if it is supposed to be supported throughout the whole of the above space, it must act with a certain pressure upon every point of the supporting mass. But its pressure will, of course, be greatest in the vertical

but the value of each of the two portions of the supported earth will remain the same, as in the former case. The statement of the question will therefore be,

$$\frac{ax^2}{2} - \frac{a^3}{6c^2} + \frac{ax^2}{2n} - \frac{x^3}{6n} = \frac{(a-x)^3}{6n}.$$

SOLUTION. $x = \sqrt{\frac{a^2}{8} + \frac{a^2}{3n} + \frac{a^2}{3c^2}} - \frac{a}{2n}.$

CASE 3. When the revetment is leaning, its given height being supposed to be $= a$, and its slopes each $= \frac{1}{c}$.

In this case, after substituting p, as the value of the expression, $1 - \frac{1}{c}$, the stability of the masonry will be represented by $\frac{a^2x}{2c} + \frac{ax^2}{2}$; the force of the stabilitating portion of the supported earth will be represented by $\frac{ax^2}{2n} - \frac{x^3}{6pn}$; and the force of the upper portion of the supported earth will be represented by $\frac{(ap-x)^3}{6pn}$: so that the statement of the question will be,

$$\frac{a^2x}{2c} + \frac{ax^2}{2} + \frac{ax^2}{2n} - \frac{x^3}{6pn} = \frac{(ap-x)^3}{6pn}.$$

SOLUTION. $x = \sqrt{\left(\frac{a}{2e} + \frac{ap}{2n}\right)^2 + \frac{a^2p^2}{3n}} - \frac{a}{2c} - \frac{ap}{2n}.$

According to these solutions, in profiles each 30 feet high, the value of x, or the thickness of masonry, in a rectangular revetment, would be $=$ 7·4109 feet: the value of x, or the thickness of masonry at bottom, in a sloping revetment, having a slope of one-fifth, would be $=$ 7·7404 feet, and the mean thickness of the masonry would be equal to 4·7404 feet: whilst

direction, o m, which corresponds with the action of gravity: it will be least in the direction, o p, which agrees nearly with the natural slope; and in any intermediate direction, such as n, it will act with greater force than in the direction, p, but with less force than in the direction, m. But on inspecting the figure, it will be evident, that the whole of the pressure, exerted by the particle of earth, o, upon that portion of the supporting mass, which lies between the points, m and a, acts upon the stabilitating mass of earth, and in all probability adds to its power of strengthening the revetment. It will also be evident, that the whole of the pressure,

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the value of x, or the thickness of masonry, measured horizontally, in a leaning revetment, also supposed to have slopes of one-fifth, would be = 4·8755 feet.

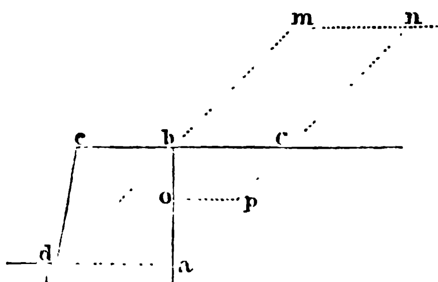
The theory, which has just been stated, occurred to me, soon after I discovered the very erroneous nature of the common hypothesis as to the pressure of earth upon revetments; and the results, obtained from the solutions, even appeared to agree with some of our first experiments: but on reflecting further upon the subject, and on trying more experiments, on a larger scale, and with a more perfect apparatus, I found that this theory also rested upon an imperfect hypothesis, although certainly much less objectionable than the common one. I do not therefore recommend that the method of estimating the strength of counterscarp revetments, which has been explained in this note, should be followed in practice, nor do I vouch for the accuracy either of the above solutions, or of others, that might be obtained by applying the same principles to scarp revetments, demi-revetments, &c. But upon the whole I judged it best to introduce them, although not strictly accurate, because to those readers, who may not have studied any of the common theories of revetments, the above will serve as a specimen of the manner, in which mathematical writers have usually attempted to reduce this subject to a matter of calculation.

As the more correct theory of revetments, which is afterwards laid down by me in the text, and corroborated by experiments, is founded upon a hypothesis of a more complex nature than the above: hence arises the difficulty, which, as I said, there will probably be, in solving it mathematically, by any convenient formula, likely to be practically useful; for even in calculating according to the very simple hypothesis assumed in this note, if we had not supposed the specific gravity of the revetment and of the supported earth to be equal, solutions of a simple nature could not have been obtained.

exerted by the same particle, in the direction of any point, such as n, which falls within the base of the revetment, must necessarily tend to add stability to the masonry; so that the only part of the pressure of the particle, o, which tends to overset the revetment, is that which is exerted in the direction of some point, such as p, which falls without the base of the wall.

From hence it follows, that the strength of any profile is as the mass of masonry contained in the revetment, and as the stabilitating portion of the supported earth, directly; both of which, in a revetment of any given description, whether rectangular, sloping, countersloping or leaning, will evidently increase in proportion to the base or mean thickness of the masonry: so much so, that by adding to the said thickness, the upper portion of the supported earth, which is the only part of it that can possibly tend to weaken the revetment, may be made entirely to disappear; and this case shall be considered the first, out of four distinct cases of revetments, that shall now be explained.

Case I. For example, in the annexed figure, if we suppose, a b c d, to represent a counterscarp or gorge revetment, whose base is equal to its height, the dotted line, d b, drawn from the front of the base, parallel to the boundary line, a c, will not, as in our former figures, cut off any portion whatever of the supported mass of earth, a b c; and consequently the whole of the said mass must add stability to the revetment, so that the masonry will become much stronger and more capable of resisting any power, that may have a tendency to overset it, after being backed with loose earth, than it was before. And in a profile of this kind,

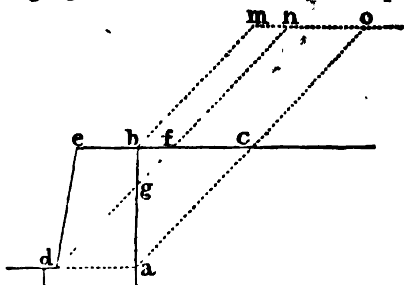


it will be evident, from the principles before laid down, that by increasing the quantity of loose earth, pressing upon the back of the revetment; as for example, by raising it to the level, m n, the stability of the profile will be increased in proportion; but if the quantity of supported earth is diminished, as for example, by lowering it to the level, o p, then the stability of the profile will be diminished in proportion; and the supposed revetment will be reduced to its weakest possible state, by clearing away the whole of the loose earth from behind it.

CASE II. But in order to produce a similar effect, namely, that the mass of supported earth, in any profile, shall, upon the whole, add stability to the masonry, it is not absolutely necessary, that the base of the revetment should be equal to its height, or that the former should bear so great a proportion to the latter, as to cause the upper portion of the supported earth entirely to disappear, as in our last figure. For although the upper portion of the supported earth, when such there is, in any profile, has always some tendency to weaken the revetment, yet it was before shewn, that even this portion does not exert the whole of its force to that effect, but a part of it only, the remainder of its force being employed in adding stability to the masonry, by pressing it downwards upon its foundation. And consequently, in those profiles, in which the base or mean thickness of the revetment are so regulated, that after the wall is backed with loose earth to the level of the top of the revetment, the upper portion of the supported earth bears a smaller ratio than usual to the stabilitating portion, it may happen that the stabilitating power, even of the former portion, singly, shall be very little inferior to its own oversetting power; so that, upon the whole, the general result of the action of the total supported mass, upon the stability of the revetment, shall be similar to that of our former case.

Thus, for instance, in the following figure, in which the mean

thickness of the counterscarp or gorge revetment, a b e d, is supposed to be rather less in proportion to its height, than in our last example, other particulars remaining the same; it may easily be understood, that the small superior portion, g b f, of the supported mass of earth can, of itself, have very little power of weakening the masonry, even if it were not counteracted in that tendency, by the much superior power of the stabilitating portion, a g f c; and therefore the same general conclusion will hold good in this, as in our former case: that is to say, the revetment, a b e d, will be in its weakest possible state, when there is no earth pressing upon it: its strength will be greatly increased by backing it in with loose earth to any given continued horizontal level, such as b c, and it may be still further increased, but cannot be diminished, by adding to the quantity of loose earth, as for example, by raising it to a higher level, m n o.



In the case, which has just been stated, it is to be observed, that although by increasing the height of loose earth from the level, b c, to m o, the upper portion, g b m n, may no longer bear a very small ratio to the stabilitating portion, a g n o, as before; yet by reason of the natural slope, b m, the additional mass of earth, b m n f, which becomes a part of the upper portion, is thrown so much to the rear of the revetment, as to exert a very considerable part of its pressure upon the base of the wall in a manner favourable to stability.*

CASE III. By reducing the proportional mean thickness of

* In reflecting upon this subject, it occurred to me, that there might be cases, in which the stabilitating power of the upper portion, g b f, of the

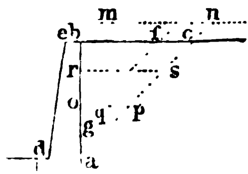
masonry of our counterscarp revetment, a certain degree less than in our second supposition, other particulars remaining the same, it may happen, that the strengthening and oversetting powers of the supported mass of earth may become exactly equal, so as to cancel each other, like equal and counteracting weights in an opposite pair of scales. When such is the case, although the weight of earth pressing upon the revetment may be very great, its effect in regard to the stability of the profile will be null, so that precisely the same power will be capable of oversetting the revetment, when backed to its proper height with loose earth, which would have been capable of oversetting it, before any earth whatever was applied to it.

CASE IV. If we suppose the mean thickness of masonry of our counterscarp revetment to be reduced, in a certain degree less than in our last supposition, other particulars remaining the same; it will then happen, that the upper portion of the supported earth may exceed the stabilitating portion in magnitude; and at the same time, that its own oversetting power may be considerably

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supported mass, might exceed its own oversetting power: so that, even the upper portion, considered singly, might tend, upon the whole, rather to strengthen, than to weaken the profile. On trying various experiments, however, to ascertain this point, some of which shall afterwards be noticed, we found that in loose soil, the upper portion of the supported mass does always appear to weaken the profile, more or less; so that, for example, in our present figure, although the substantial revetment, a b e d, has greater stability, when backed with the mass of loose earth, a b c, than if there were no earth at all applied to it; its stability would be still further increased by removing from the said mass, the upper portion, g b f, and leaving only the lower portion, a g f c, to press against the back of the masonry. In like manner, the same revetment, a b e d, will have more stability, when backed with the mass of loose earth, a b m o, than if there were no earth applied; but its stability will be greatest of all, when the upper portion, g b m n, of the said mass is removed, leaving only the lower portion of it, a g n o, to act upon the back of the masonry.

greater than its strengthening power. When such is the case, the revetment will be much weaker when backed with loose earth, than if there were none; so that it will overset at a certain height by the mere pressure of earth acting upon it; but even in this case, as in our former ones, some portion of the supported earth will always tend to give stability to the masonry.

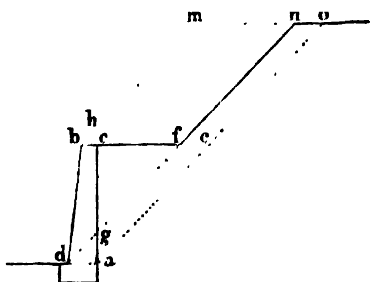


For example, a b c d, in the annexed figure, may represent a counterscarp revetment of this description, which is so proportioned, that after backing it with loose earth, to the level, e c, of the top of the masonry, it will barely be able to resist the pressure; by reason of the great ratio, which the superior portion of the supported earth, g b f, bears to the stabilitating portion, a g f c, as well as on account of the inconsiderable power, which either of them can exert upon so small a base, as that of our present revetment. In a profile of this description, any the least addition to the quantity of loose earth, pressing on the back of the revetment, as for example, by raising it to the level, m n, would instantly overthrow the wall. If, on the contrary, we suppose the quantity of loose earth pressing upon our counterscarp revetment to be diminished, as for example, by lowering it to the level, r s, its oversetting power will also be diminished in proportion, so much so, that the action of the loose earth may come under the third case; that is to say, the revetment may neither gain nor lose in stability, by being so loaded. Again, if we suppose the quantity of loose earth to be still further diminished, as for example, by lowering it to the level, o p, the upper portion, g o q, of the supported mass, may then bear so small a ratio to the stabilitating portion, a g q p, that the circumstances may come to agree with those of our second case; that is to say, the revetment, when backed to the level, o p, will become somewhat stronger, than if there were no loose earth pressing upon it.

Having now stated the four general cases of revetments, it is to be remarked, that the two former are not suitable for practice, as they evidently imply a much greater strength of masonry, than can be necessary, for supporting the pressure of loose earth acting upon them. The third case, or even a profile in some degree weaker, is suitable for revetments without counterforts, when such are used. The fourth case, in which the masonry is barely capable of resisting the pressure of earth acting upon it, may, by the addition of well-proportioned counterforts, be rendered sufficiently strong and fit for practical purposes.

With regard to the effect produced upon the stability of partial revetments by a berm, it may be observed, that this also will, in a great measure, depend upon the proportion which the base or mean thickness of the masonry bears to its height. If the proportional thickness is inconsiderable, such profiles will be stronger, by allowing them a berm; but if their proportional thickness should be increased beyond a certain limit, they will then be stronger without one.

For example, in the annexed figure, if we suppose the mean thickness of the revetment, a c b d, to be so small, in proportion to its height, that it is barely strong enough for resisting the pressure of loose earth, when raised to the level, e c, of the top of the supposed masonry; it will be evident, that after allowing a berm of sufficient breadth, such as b f, the mass of loose earth may be increased, by raising it to any given height, n o, above



the revetment, without prejudice to the strength of the profile; for by this arrangement the additional mass of loose earth, f n o e, may be thrown so much to the rear, as to act solely upon, and to

co-operate with, the stabilitating portion, a g f e, of the original supported mass pressing upon the revetment, the effect of which will be favourable. But if the loose earth were supposed to be raised to an equal height, m n o, above the same revetment, without allowing any berm; then so great an additional mass, b h m n f, will be made to co-operate with the upper portion, g c f, of the original mass of supported earth, that the revetment will be unable to resist their united efforts, tending to overset it. With respect to the small additional triangle, c b h, it is true, that by pressing vertically downwards, upon the top of the revetment, it acts with its whole weight in a manner favourable to stability; but in thin profiles, like that which is now under consideration, this triangle forms by far too inconsiderable a portion of the total additional mass, b m n f, to be of any effectual assistance to the revetment, which, if loaded with loose earth to a certain height, without allowing a berm, must necessarily fall, as was before asserted.

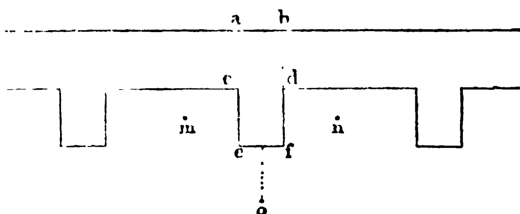
To illustrate more fully the principle which has been stated, in a second figure, drawn similar to the former, in other respects, let A C B D represent a new revetment, whose mean thickness bears a much greater ratio to its height, than that which has just been commented upon. Then it will be evident, that if the loose earth pressing upon this new revetment, should be raised from the level, C E, to the height, N O, allowing a broad berm, such as B F, the additional mass, F N O E, will act upon and be made to co-operate with the stabilitating portion, A G F E, of the original earth pressing upon the revetment; and this, according to the principles before laid down, will tend to increase the stability of the profile, in a certain degree. But if the earth should be raised to the same height, M N O, without allowing any berm,

the strength of the profile will be still further increased; for the additional triangle, C B H, acting vertically, which in our former profile was insignificant, will, in our new profile, by reason of the greater thickness of masonry, become so considerable, as to have very great power in preventing the revetment from oversetting; whilst, by the same reason, the remainder of the additional mass, C H M N F, although bearing upon the superior portion, G E F, of the originally supported earth, will be thrown so much to the rear, as to press with a considerable force, and with an effect also favourable to stability, upon the base, A D, of the revetment. Thus, upon the whole, our present substantial profile, A C B D, if used as a partial revetment, will be stronger without a berm than with one.

From the same reasoning, it will be obvious, that when a partial revetment, of inconsiderable thickness, is constructed with counterforts, a contrary effect may be produced upon the several portions of the profile, by the use or disuse of a berm. For example, the revetment itself, in general, may be weakened, by raising the loose earth over it to a certain height, without allowing a berm; whereas, those particular portions of it, that are supported by counterforts in rear, may, by reason of their superior depth or general thickness of masonry, be greatly strengthened, in consequence of the same construction.

We shall next take into consideration the peculiar effect produced by counterforts in strengthening a revetment. In this inquiry, the first obvious principle, which naturally presents itself, is, that, as far as regards the pressure of loose earth in rear, only, in any revetment, constructed with counterforts, those particular portions of the masonry, which are supported by a counterfort, will have a stability equal to that of a simple profile, of the same height, without counterforts, whose thickness shall be equal to the total thickness or depth of masonry, contained in the first revetment, and in one of its counterforts, added together. Thus, for example, in the an-

nexed sketch, which represents the foundation plan of a rectangular wall with counterforts, if we suppose the height to be 20 feet; the thickness, a c, of the revetment, to be 5 feet; and the length (c e) of the counterforts also to be 5 feet; it will be evident, that as far as regards the pressure of loose earth acting immediately in rear of it, the stability of any portion, e a b f, of the profile, which includes a counterfort, will be the same as that of a similar portion of another rectangular profile, without counterforts, also 20 feet high, but having a thickness of 10 feet, which is equal to the total thickness or depth of masonry, a e, contained in a continued section, taken from the front of the revetment, represented in our present figure, through one of its counterforts.



But it is further to be remarked, that in all revetments having counterforts, the pressure of loose earth retained does not only act upon the rear, but also upon the sides of every individual counterfort, such as, c e f d, in our figure. For example, if we suppose the points, o, m, and n, to be equally distant, the former from the rear, the two latter from the sides of the said counterfort, they may represent loose particles of the retained earth, situated on the same horizontal level, at a considerable height above the base of the masonry. It is almost needless to repeat, what was before observed, that loose earth has a tendency to act in a circle, in every direction, but always at a certain angle downwards;* conse-

* The scope of action of a particle of shingle or loose earth, may be represented by an upright cone, of indefinite depth, of which the said particle is supposed to be placed at the vertex; and whose sides slope in such a manner, that in a vertical section, the angle at the vertex shall either be a right angle, or a little greater.

quently, the two particles, m and n, will not only press against the back of the revetment immediately in front of them, but also against the sides, c e, and d f, of any counterfort such as, c e f d, which is to the right or left of them, upon which they will each act, with a force equal to that, wherewith any equidistant particle, o, acts against the back of it. But it must be evident, that the pressure, exerted by the particles, m and n, on opposite sides of the counterfort, cannot have the least tendency to overset it: on the contrary, these particles jam or grasp it between them with great force, in the same manner that a blacksmith's vice grasps the sides of a piece of iron; and as the same reasoning which applies to any individual particles, such as, m, n, and o, applies to all other particles, composing the total mass of retained earth; it follows, that whatever tendency there may be in the pressure of loose earth acting on the back (e f) of any counterfort (c e f d) to overset the profile, this tendency is powerfully counteracted by the pressure of the same material, acting upon the sides of it (c e, and d f). And, from these considerations, it will appear, that in a revetment, built with counterforts, the stability of any portion (e a b f) of the profile, which includes a counterfort, will not merely be equal to, but will be much greater than, the stability of an equal and similar portion of another revetment, built without counterforts, but of the same height, and having a thickness of masonry (a e) equal to the total thickness or depth of masonry, contained in a continued section, taken from the front of the first revetment through one of its counterforts.*

Here it may be remarked, that this is another part of their subject, in which all the theoretical writers upon revetments have

* In consequence of the great additional stability, arising from the pressure on the sides of counterforts, it will often happen, that a revetment of any given thickness (such as 5 feet), and having counterforts of a given

fallen into error; for none of them have taken the least notice of the pressure of the supported earth, upon the sides of counterforts, which has been shown to act in a manner so very favourable to stability: and accordingly, in consequence of this omission, the various theories of revetments, that have hitherto been published, if applied to profiles with counterforts, yield results still more glaringly erroneous, than when they are applied to simple profiles without counterforts.

Having thus explained the various effects produced by the pressure of loose earth upon revetments; having shown, that this pressure does not always tend to overset or weaken, but that, in certain cases, it may greatly strengthen a profile; having also shown, that, in some cases, a berm may be prejudicial to the stability of a partial revetment; both of which positions are equally contrary to received opinions; and having lastly explained an important advantage, arising from the use of counterforts, which appears to have been hitherto entirely overlooked; I shall remark, that although the truth of these new principles upon the subject of revetments, will probably appear sufficiently obvious, from what has already been said; yet I conceive, that it would be a vain task to attempt to determine, by reasoning or calculation alone, what particular dimensions ought to be given to a profile of a certain description, in order to bring it exactly under any one of the various cases of

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length (which we shall also suppose to be 5 feet), may gain in stability by being backed with loose shingle to any given height: whilst another revetment, without counterforts, of the same height, and having a thickness (of 10 feet, which is) equal to the total depth of masonry in the strongest parts of the former, will not gain, but lose, in stability, by being backed with shingle to a similar height, and under similar circumstances.

The truth of this observation will be proved by referring to the tables of experiments with shingle afterwards given, in which compare experiments 109, 110, 111, 112, 113, in Table IV, with experiments 62, 63, 64, 65, 66, in Table III. Compare also experiments 119, 120, 121, 122, 123, in Table IV, with experiments 72, 73, 74, 75, 76, in Table III, &c. &c.

revetments, which have been discussed. And therefore, without enlarging further upon general principles, I shall now proceed to state the experiments before alluded to, which were recently tried, at Chatham, under my directions.*

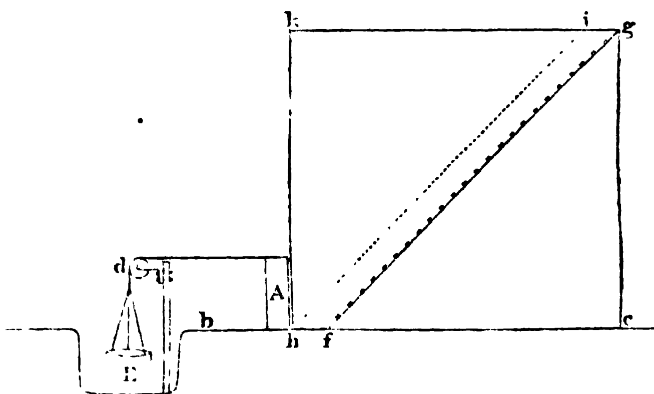
A certain number of wooden cases, which shall afterwards be more particularly described, were prepared and filled with rammed earth, so as to weigh about 84 lbs. per cubic foot. They were all three feet long, and most of them 26 inches high, but their mean thickness and slopes differed, in order that they might represent revetments of various kinds and proportions. Most of our experiments upon these models were tried with loose shingle perfectly dry, which when thrown up to the height of 5 feet assumed a slope, whose base was about 6 feet 3 inches. At smaller heights it might be made to stand a little steeper, but in no case at a less slope, than that of 1 to 1. A cubic foot of this substance weighed 89 lbs.

When any experiment was to be tried, one of the models was placed on its base, in the position, A, upon a smooth plane of wood, b c, as represented in the annexed figure. To the back of the top of the model was fixed one end of a string, which after passing horizontally over a pulley, d, hung down and supported a

* They were commenced by Lieut. Montgomery Williams of the Royal Engineers, with a select party of intelligent non-commissioned officers and privates. That officer tried personally nearly the whole of the experiments with shingle contained in the first seven Tables, after which, on his being removed to another station, I gave the charge of the party to Serjeant Daniel O'Bryen, who had previously assisted Lieut. Williams, and who completed the remainder of the experiments recorded in this chapter, with the exception of some that were tried by Serjeant Foster Taylor. The same process was in all cases repeated several times, for the sake of accuracy, taking the mean of the various results, as the definitive conclusion to be drawn from each experiment. I was frequently present, and am satisfied as to the accuracy, with which the various trials were made.

scale, E, for holding weights. After the model was thus arranged, a trial was first made, by means of the scale, to ascertain what weight was required to overset it, without any shingle or loose earth being applied to it. This being done, the model was then replaced in the same position, and backed with shingle to a certain height, according to the nature of the proposed experiment; and if it did not overset in consequence of the pressure, thus acting upon it, weights were put into the scale, as before, in order to ascertain the increase or diminution of stability caused by the shingle.

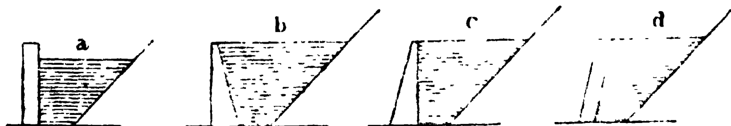
It is to be observed, that a rough board, f g, sloping at an angle of rather less than 45 degrees, was placed about one foot in rear



of the bottom of the model: so that in whatever mode the mass of shingle might be applied to the supposed revetment, it was always bounded and supported in rear by the board. This was done in order to save the men employed from unnecessary labour, in throwing up a superfluous quantity of that material; it being evident that no part of the mass of shingle, which was behind the dotted line, h i, drawn parallel to f g, could possibly affect the revetment. For the same reason, the space, in which the shingle was thrown up, was bounded, on each side, by two smooth planes of

wood work, placed vertically and parallel to each other, one of which is shown in elevation by the rectangle, h k g c; their distance apart being about 3 feet 1 inch; that is to say, a small degree more than the length of each model: and great care was taken, in every experiment, that the model should not be prevented from falling, by any particles of shingle getting jammed between the ends of it, and the above planes; for which reason it was placed immediately in front of, but yet as near to them, as possible, in the manner shown in the figure.* By reason of the small height of our models, it was necessary to dig a hole in front, in order to make room for the free action of the scale and weights. All our experiments were tried under cover, this precaution having been found essential to accuracy.

The first set of models made, represented by the letters, a, b, c, and d, in the annexed figures, were all 26 inches high; had a thickness or mean thickness of 4 inches, and weighed each of them 182 lbs. The model, a, represents a rectangular revetment; b, represents a countersloping revetment, having a counterslope of one fifth; c, represents a sloping revetment, having a slope of one fifth; and d, represents a leaning revetment, also having slopes of one fifth.



On trying the stability of these profiles, in the manner before described, we found that the rectangular model, a, required a

* When countersloping or leaning models were used, small triangular pieces of plank, cut so as to correspond with the slope of the back of the supposed revetment, were added to the lower part of the front, h k, of each of the wooden planes.

weight of 12 lbs. to overset it without shingle; but on backing it with that material, in order to represent a counterscarp revetment, it fell of itself without any weight being used, as soon as the shingle was raised to the height of 22 inches above the base, that is to say, 4 inches lower than the top of the model. (*See, in the following Tables of Experiments, Tab.* I. *Exp. No.* 1.)*

The stability of the countersloping model, b, without shingle, proved to be 12½ lbs. On backing it so as to represent a counterscarp revetment, it also fell of itself, without using any weights, as soon as the shingle was raised to the level of the top of the model. (*See Tab.* I. *Exp.* 11.)

The stability of the sloping model, c, without shingle, proved to be 27 lbs. When backed to the level of the top of the model, so as to represent a counterscarp revetment, it required a weight of 5½ lbs. in addition to the pressure of the shingle to overset it. The original stability of this model being therefore equal to 27 lbs. and its stability as a counterscarp revetment only 5½ lbs.; it follows, that the stability lost, in consequence of the pressure of the shingle, may be estimated at 21½ lbs. (*See Tab.* I. *Exp.* 5.)

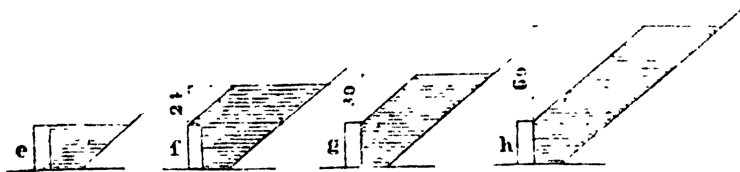
The stability of the leaning model, d, without shingle, was

* In our various experiments with shingle, the models were always observed to move a little, after the application of a certain weight, which however proved incapable of oversetting them. The weight required to move any model, in the manner alluded to, in a small degree out of its original position, which was done by pulling the top of it forwards, whilst the front of the base appeared to remain at rest, amounted usually to about three fourths of the total weight, or even more, when the models had counterforts attached to them; but when tried without counterforts, the weight which first moved our models, was, in general, rather less than two thirds of the oversetting weight. It did not, however, in any case, fall short of one half of the latter. Several intermediate movements or changes of position usually took place, between the first movement and the fall of our models.

25 lbs.;* but as a counterscarp revetment its stability proved to be only 6¾ lbs.; so that the stability lost in this profile, by reason of the shingle, appeared to be 18¾ lbs. (*See Tab.* I. *Exp.* 8.)

From the above experiments, we concluded, that any profile without counterforts, even having so considerable a slope as one fifth, whose mean thickness is two thirteenths of its height only, will not by any means be strong enough, either for a gorge or counterscarp revetment, in fortification, or for the retaining wall of a wharf, &c., in civil works. We therefore had a new set of more substantial models made, also 26 inches high, but having a thickness or mean thickness of 8 inches. Each of these new models, being double of the former in cubic contents, weighed 364 lbs.

On trying the new rectangular profile, whose dimensions have just been stated, its stability without shingle was 47 lbs.; but on backing it with that material, so as to represent a counterscarp revetment, in the manner shown in fig. e, its stability proved to be only 30 lbs.; the loss of stability, occasioned by the pressure of the shingle, being therefore equal to 17 lbs. (*See Tab.* II. *Exp.* 43.)



We next tried the same rectangular model, as a scarp revet-

* That is to say, its stability as opposed to a pressure in rear. In a contrary direction, by reason of the smallness of its base, it had none, but even required some support to prevent it from falling. The same happened in one of our other leaning models, in which the thickness was so inconsiderable, that a vertical line, dropt from the centre of gravity, also fell without the base.

ment without a berm, heaping shingle above it, in the manner shown in fig. f. As soon as this material was raised 24 inches higher than the top of the supposed revetment, the model fell of itself, by the pressure of the shingle, without any weights being used. (*See Tab.* II. *Exp.* 44.)

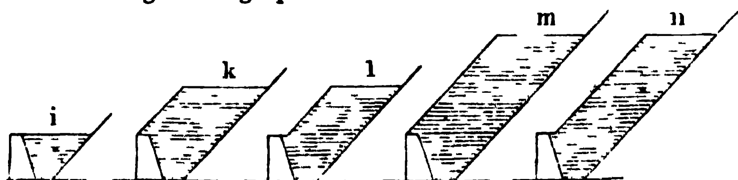
On allowing a berm of 8 inches, the stability of the same rectangular model, when the shingle was raised 30 inches higher than the top of it, in the manner shown in fig. g, proved to be 14 lbs.

And on afterwards raising the shingle to the height of 60 inches, with a berm of the same breadth, in the manner shown in fig. h, the stability of the model proved to be 13 lbs. (*See Tab.* II. *Exps.* 45 *and* 46.)

We next tried the countersloping model, whose height was 26 inches, its mean thickness 8 inches, and its counterslope one fifth of the height, under the several following circumstances:

First, we ascertained its stability without shingle, which proved to be 51 lbs.

Secondly, we tried it as a counterscarp revetment,, by backing it with shingle, in the manner represented by fig. i, which being done, its stability proved to be 80 lbs.: so that a countersloping model of the above description appears, in this case, to gain an additional stability of 29 lbs., in consequence of the pressure of the loose shingle acting upon it.



Thirdly, we heaped shingle over the top of the model to the height of 30 inches, without a berm, in the manner shown in fig. k, which being done, its stability proved to be 70 lbs.

Fourthly, we raised the shingle as before to the height of 30

inches over the top of the model, but left a berm of 8 inches, as in fig. l. In this case the stability of the profile proved to be 82 lbs.

Fifthly, we raised shingle over the model to the height of 60 inches, without a berm, as in fig. m, and found that the stability in this case was 65 lbs.

Sixthly, we raised the shingle, as in the preceding experiment, to the height of 60 inches, but left a berm of 8 inches, as in fig. n, which being done, the stability of the profile proved to be 80 lbs. *(For the last-mentioned Experiments, see Tab.* III. *Exps.* 72, 73, 74, 75 *and* 76.)*

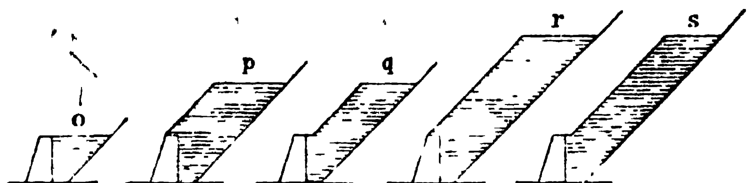
We then tried the sloping model, whose height was 26 inches, its mean thickness 8 inches, and its slope one-fifth, under pre-

* In experiment i, the weight of shingle actually supported by and pressing upon the back of the model, may be estimated at 908 lbs.; but in experiment n, it may be estimated at 4890 lbs.: hence, as the model itself weighed only 364 lbs., our supposed revetment was loaded, in one case, with about $2\frac{1}{2}$ times its own weight of shingle, and, in the other, with more than 13 times its own weight of shingle, and yet in both cases its stability proved much greater than it had been before any pressure whatever was applied to it; and in both cases, too, the stability was found to be equal, although the pressure of the loose material, in the one case, exceeded that of the other in a five-fold ratio. The above results expose, in the strongest light, the very erroneous nature of the commonly received hypothesis, according to which, the profile, n, as compared with the profile, i, ought to have had no stability whatever, unless the dimensions of the supposed revetment had been increased in proportion to the excess of pressure.

According to Vauban's rule, for example, which was before stated in page 523, whatever thickness might be proper for the supposed revetment, used in fig. i, that thickness ought to have been increased by one fifth part of 60, in order to produce a profile proportionally strong, for the partially reveted figures, m, and n. Consequently, as the model, i, has a mean thickness of 8 inches, the model, n, ought, by the above erroneous hypothesis, to have had a mean thickness of no less than 20 inches, in order to possess a stability equal to that of the former.

cisely the same circumstances as the last, and found the following results:

Its stability without shingle proved to be 85 lbs.



Its stability, as a counterscarp revetment, as in fig. o, proved to be 77 lbs.

Its stability, with 30 inches of shingle over it, and no berm, as in fig. p, proved to be 60 lbs.

Its stability, with 30 inches of shingle over it, and a berm of 8 inches, as in fig. q, proved to be 63 lbs.

Its stability, with 60 inches of shingle over it, and no berm, as in fig. r, proved to be 64 lbs.

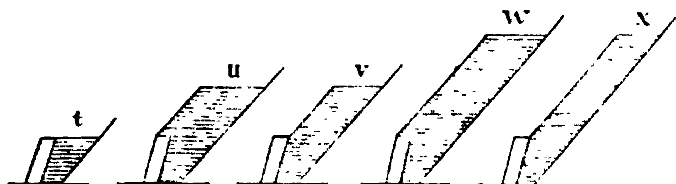
And its stability, with 60 inches of shingle over it, and a berm of 8 inches, as in fig. s, proved to be 65 lbs. *(See Tab.* III. *Exps.* 62, 63, 64, 65, *and* 66.)*

We next tried the leaning model, whose height was 26 inches,

* As a second example of the gross practical errors, to which the common hypothesis of the pressure of earth upon revetments may lead, I shall remark, that if the dimensions necessary for a partially reveted profile, such as s, having a berm equal in width to the thickness of masonry, had been calculated according to the theory of Professor Muller, the sloping model used, instead of 8 inches, which proved to be sufficiently strong, ought to have had a mean thickness of about 40 inches, which is more than 1½ times its height; and, in addition, it ought also to have had counterforts, 6½ inches long, and placed at central intervals of four times their width apart. *(See Muller's Practical Fortification, Section* I.)

its horizontal thickness 8 inches, and its slopes equal to one-fifth of the height, and found the following results:

Its stability without shingle proved to be 86 lbs.



Its stability, as a counterscarp revetment, as in fig. t, proved to be 110 lbs.

Its stability with 30 inches of shingle over it, and no berm, as in fig. u, proved to be 67 lbs.

Its stability, with 30 inches of shingle over it, and a berm of 8 inches, as in fig. v, proved also to be 67 lbs.

Its stability, with 60 inches of shingle over it, and no berm, as in fig. w, proved to be 68 lbs.

And its stability, with 60 inches of shingle over it, and a berm of 8 inches, as in fig. x, proved to be 62 lbs. (*See Table* III. *Exps.* 67, 68, 69, 70 *and* 71.)

From the above experiments, with the larger kind of models, that have last been described, we concluded, that in walls without counterforts, whose mean thickness is equal to four thirteenths of the height, the rectangular profile is strong enough for a counterscarp or gorge revetment, or for the retaining wall of a wharf, &c. but that it is too weak for the scarp revetment of a work of fortification; whilst by reason of the great additional strength, produced by slopes of one fifth, the other forms that have been taken into consideration, namely, the countersloping, sloping, and leaning profiles, of the same cubic contents as the former, are each fully strong enough, not only for counterscarp or gorge revetments, but

also for demirevetments or partial scarp revetments, having earthen slopes of any given height, whether with or without a berm, above the masonry.

Having thus ascertained, that the first set of models were too weak to represent a well proportioned revetment, and it appearing probable, that the second set might be stronger than was absolutely necessary for that purpose, we next tried a third set of models, also 26 inches high, but having each a thickness or mean thickness of 6 inches, so that they were exactly of a medium size between the two kinds, that have been already described. These were also rectangular, countersloping at one fifth, sloping at one fifth, and leaning at one fifth. Afterwards, in order to ascertain the difference of stability that would be caused in the several sloping profiles, by diminishing the slope from one fifth to one eighth of the height, we had other models made according to the last mentioned slope, but corresponding with the former models in height and mean thickness. Lastly, to each of the several models that have been enumerated, we fixed a couple of rectangular counterforts, made of the same materials as the models themselves. These were all 26 inches high, and generally 4½ inches wide, and placed at central intervals of 18 inches apart, and were likewise generally, but not always, equal in length to the mean thickness of the model, to which they were attached; so that the weight of the counterforts, added together, was, in most cases, one fourth of the weight of their supposed revetment. The stability of each of the new profiles thus formed, was also tried with shingle, at various heights, both with and without berms, in the same manner, and under the same circumstances, as the former.

In order to enable the reader to form a clear general view of the results, obtained by the numerous experiments alluded to, without fatiguing his attention by a detailed statement of the whole

of them in words, I have thrown them into the form of tables, each experiment being numbered for the sake of reference. The column in each table, which marks the height of shingle or earth, denotes the said height, as measured above the top of the model, or supposed revetment; so that when no number is placed under that column, it implies that the shingle or earth is raised to the level of the top of the model, which accordingly will, in this case, represent a counterscarp revetment; but if there should be any number written under that heading, with the negative sign — prefixed to it, it implies that the shingle or earth is so much lower than the top of the model. The berm, when such appears, in any of the experiments, is always supposed to be equal in width to the thickness or mean thickness of the supposed revetment. When, in any particular experiment, no number is written beneath the column of stability, it denotes, that the model fell, under the circumstances stated in that experiment, by the pressure of the shingle alone, without any weights being used. Those numbers in the tables, which denote weight or stability, are all in pounds: the dimensions are in inches.

Having premised so much in explanation of the tables, I shall now proceed to lay the first course of experiments, that were made with shingle, before my readers. They are as follows:*

* An idea also occurred to us of trying experiments of a similar nature with small shot; but on further reflection, we judged, that such experiments could not lead to any useful practical result, because that material is much looser, than any that can ever possibly press upon a real revetment. We, therefore, in conducting our general course of experiments, pitched upon shingle and rammed earth, as the two extremes; the former being the loosest, and the latter the most tenacious kind of soil, that can occur in real practice.

TABLE I.

Models standing loose.	Without Shingle. The Revetment's Height.	Mean Thickness.	Weight.	Stability.	With Shingle. Height of Shingle.	Berm = Mean Thicks.	Stability.	No. of the Experiment.
Rectangular.	26	4	182	12	—4	....	0	1
Sloping at 1/8.	26	4	182	23	½	....	0	2
Leaning at 1/8.	26	4	182	24	—1	No	0	3
Countersloping at 1/8.	26	4	182	12¼	—1	....	0	4
Sloping at 1/5.	26	4	182	27	....	....	5½	5
					3	No	0	6
					10	Yes	0	7
Leaning at 1/5.	26	4	182	25	....	....	6½	8
					3	No	0	9
					7	Yes	0	10
Countersloping at 1/5.	26	4	182	12½	....	....	0	11
Rectangular.	26	6	273	27	....	....	4½	12
					5	No	0	13
					5	Yes	0	14
Sloping at 1/8.	26	6	273	43	....	....	23	15
					30	No	5	16
					30	Yes	14	17
					60	No	15	18
					60	Yes	15	19
Leaning at 1/8.	26	6	273	46	....	....	26	20
					30	No	5	21
					30	Yes	12	22
					60	No	16	23
					60	Yes	14	24
Countersloping at 1/8.	26	6	273	27½	....	....	10	25
					6½	No	0	26
					12	Yes	0	27
Sloping at 1/5.	26	6	273	51	....	....	35	28
					30	No	20	29
					30	Yes	29½	30
					60	No	18	31
					60	Yes	25	32

TABLE II.

Models standing loose.	Without Shingle. The Revetment's Height.	Without Shingle. The Revetment's Mean Thickness.	Without Shingle. The Revetment's Weight.	Without Shingle. The Revetment's Stability.	With Shingle. Height of Shingle.	With Shingle. Berm = Mean Thicks.	With Shingle. Stability.	No. of the Experiment.
Leaning at $\frac{1}{5}$.	26	6	273	59	....	....	43	33
					30	No	35	34
					30	Yes	35	35
					60	No	34½	36
					60	Yes	34	37
Countersloping at $\frac{1}{5}$.	26	6	273	29	....	....	23	38
					30	No	10	39
					30	Yes	20	40
					60	No	12	41
					60	Yes	30	42
Rectangular.	26	8	364	47	....	....	30	43
					24	No	0	44
					30	Yes	14	45
					60	Yes	13	46
Sloping at $\frac{1}{8}$.	26	8	364	77	....	....	64	47
					30	No	53	48
					30	Yes	53	49
					60	No	53	50
					60	Yes	53	51
Leaning at $\frac{1}{8}$.	26	8	364	68	....	....	48	52
					30	No	37	53
					30	Yes	36	54
					60	No	32	55
					60	Yes	36	56
Countersloping at $\frac{1}{8}$.	26	8	364	53	....	....	58	57
					30	No	35	58
					30	Yes	39	59
					60	No	46	60
					60	Yes	48	61

TABLE III.

Models standing loose.	Without Shingle. The Revetment's Height.	Mean Thickness.	Weight.	Stability.	With Shingle. Height of Shingle.	Berm = Mean Thicks.	Stability.	No. of the Experiment.
					....	....	77	62
					30	No	60	63
Sloping at 1/5.	26	8	364	85	30	Yes	63	64
					60	No	64	65
					60	Yes	65	66
					....	....	110	67
					30	No	67	68
Leaning at 1/5.	26	8	361	86	30	Yes	67	69
					60	No	68	70
					60	Yes	62	71
					....	...	80	72
					30	No	70	73
Countersloping at 1/5.	26	8	364	51	30	Yes	82	74
					60	No	65	75
					60	Yes	80	76
					....	...	37	77
Sloping at 1/5.	52	8	728	116	$4\frac{1}{4}$	No	0	78
					8	Yes	0	79
Countersloping at 1/5.	52	8	728	55	—1	....	0	80
Rectangular.	52	12	1092	112	....	....	18	81
					5	Yes	0	82
					....	....	116	83
Leaning at 1/8.	52	12	1092	189	36	No	0	84
					60	Yes	58	85
					...	....	133	86
Leaning at 1/5.	52	12	1092	230	30	No	70	87
					60	No	85	88
					60	Yes	100	89

TABLE IV.

Models standing loose.	Without Shingle.							With Shingle.			No. of the Experiment.
	Revetment.		Counterforts.			Total.					
	Height.	Mean Thickness.	Length.	Width.	Cent. Interval.	Weight.	Stability.	Height of Shingle.	Berm = Mean Thicks.	Stability.	
Rectangular.	26	4	4	4½	18	227½	22	...	...	19	90
								14	No	0	91
								30	Yes	7	92
								60	Yes	9	93
Sloping at ⅛.	26	4	4	4½	18	227½	35	...	...	35	94
								30	No	25	95
								30	Yes	36	96
								60	No	39	97
								60	Yes	37	98
Leaning at ⅛.	26	4	4	4½	18	227½	37	...	...	37	99
								30	No	27	100
								30	Yes	27	101
								60	No	27	102
								60	Yes	24	103
Countersloping ⅛	26	4	4	4½	18	227½	23	...	...	36	104
								30	No	18	105
								30	Yes	20	106
								60	No	36	107
								60	Yes	35	108
Sloping at ⅕.	26	4	4	4½	18	227½	41	...	...	51	109
								30	No	47½	110
								30	Yes	47	111
								60	No	44	112
								60	Yes	44	113
Leaning at ⅕.	26	4	4	4½	18	227½	43	...	...	46	114
								30	No	47	115
								30	Yes	40	116
								60	No	45	117
								60	Yes	40	118
Countersloping ⅕.	26	4	4	4½	18	227½	23	...	...	55	119
								30	No	37	120
								30	Yes	52	121
								60	No	49	122
								60	Yes	62	123

TABLE V.

Models standing loose.	Without Shingle. Revetm[t]. Height.	Revetm[t]. Mean Thickness.	Counterforts. Length.	Counterforts. Width.	Counterforts. Cent. Interval.	Total. Weight.	Total. Stability.	With Shingle. Height of Shingle.	Berm = Mean Thicks.	Stability.	No. of the Experiment.
Rectangular.	26	6	6	4½	18	341¼	54	...	. .	76	124
								30	No	66	125
								30	Yes	74	126
								60	No	70	127
								60	Yes	73	128
Sloping at 1/8.	26	6	6	4½	18	341¼	70	...	...	96	129
								30	No	98	130
								30	Yes	95	131
								60	No	107	132
								60	Yes	96	133
Leaning at 1/8.	26	6	6	4½	18	341¼	73	...	...	97	134
								30	No	95	135
								30	Yes	97	136
								60	No	95	137
								60	Yes	98	138
Countersloping 1/8.	26	6	6	4½	18	341¼	54	...	...	75	139
								30	No	94	140
								30	Yes	97	141
								60	No	81	142
								60	Yes	81	143
Sloping at 1/5.	26	6	6	4½	18	341¼	84	...	...	117	144
								30	No	121	145
								30	Yes	120	146
								60	No	120	147
								60	Yes	122	148
Leaning at 1/5.	26	6	6	4½	18	341¼	92	...	...	117	149
								30	No	138	150
								30	Yes	117	151
								60	No	134	152
								60	Yes	119	153
Countersloping 1/5.	26	6	6	4½	18	341¼	55	...	...	112	154
								30	No	118	155
								30	Yes	113	156
								60	No	124	157
								60	Yes	124	158

TABLE VI.

Models standing loose.	Without Shingle.							With Shingle.			No. of the Experiment.
	Revetm[t]		Counterforts.			Total.					
	Height.	Mean Thickness.	Length.	Width.	Cent. Interval.	Weight.	Stability.	Height of Shingle.	Berm = Mean Thicks.	Stability.	
Rectangular.	26	8	4	4½	18	409½	60	. . .	. . .	73	159
								30	No	74	160
								30	Yes	74	161
								60	No	73	162
								60	Yes	73¼	163
Sloping at 1/5.	26	8	4	4½	18	409½	99	. . .	. . .	128	164
								30	No	141	165
								30	Yes	134	166
								60	No	148	167
								60	Yes	136	168
Leaning at 1/5.	26	8	4	4½	18	409½	101	. . .	. . .	115	169
								30	No	135	170
								30	Yes	116	171
								60	No	140	172
								60	Yes	125	173
Countersloping 1/5.	26	8	4	4½	18	409½	62	. . .	. . .	150	174
								30	No	160	175
								30	Yes	156	176
								60	No	160	177
								60	Yes	153	178
Rectangular.	26	8	6	4½	18	432¼	71	. . .	. . .	106	179
								30	No	130	180
								30	Yes	103	181
								60	No	119	182
								60	Yes	101	183
Sloping at 1/5.	26	8	6	4½	18	432¼	116	. . .	. . .	166	184
								30	No	191	185
								30	Yes	171	186
								60	No	180	187
								60	Yes	171	188

TABLE VII.

Models standing loose.	Without Shingle							With Shingle.			
	Revetm^t		Counterforts			Total.					
	Height.	Mean Thickness	Length.	Width.	Cent. Interval.	Weight.	Stability.	Height of Shingle.	Berm = Mean Thicks.	Stability.	No. of the Experiment.
								...	...	145	189
								30	No	169	190
Leaning at 1/5.	26	8	6	4½	18	432¼	114	30	Yes	150	191
								60	No	168	192
								60	Yes	145	193
								...	...	199	194
								30	No	202	195
Countersloping 1/5.	26	8	6	4½	18	432¼	74	30	Yes	186	196
								60	No	215	197
								60	Yes	210	198
								...	...	120	199
								30	No	169	200
Rectangular.	26	8	8	4½	18	455	84	32	Yes	149	201
								60	No	165	202
								60	Yes	153	203
								...	...	204	204
								30	No	252	205
Sloping at 1/5.	26	8	8	4½	18	455	127	30	Yes	228	206
								60	No	272	207
								60	Yes	228	208
								...	...	195	209
								30	No	270	210
Leaning at 1/5.	26	8	8	4½	18	455	135	30*	Yes	225	211
								60	No	255	212
								60	Yes	222	213
								...	...	208	214
								30	No	229	215
Countersloping 1/5.	26	8	8	4½	18	455	96	30	Yes	223	216
								60	No	235	217
								60	Yes	228	218

Notwithstanding that it seemed to be fully proved by the above experiments, that a mean thickness, equal to four thirteenths of the height, was greater than could be required for revetments in general, I afterwards, with a view to render our course more complete, had three additional sets of models made, more substantial even than the said proportion, each of which was, like the former, 26 inches high, but of which one had a mean thickness of 10 inches, another had a mean thickness of 12 inches, and the third had a mean thickness of 20 inches.

On trying the two first of these new models with shingle, in the manner before described, we found, that there was not, by any means, that general coincidence and regularity, in the various results which had been remarked in our former experiments. But when we came to try the third and largest model, alluded to, the weight required to overset it, under precisely the same circumstances, varied exceedingly, in our different trials, the difference sometimes being not less than 100 lbs. so that it was impossible, in any particular experiment, to choose a satisfactory mean number to express the average stability; and independent of this irregularity, there was another peculiar circumstance, equally unsatisfactory, attending these new models; namely, that they did not, like the former ones, gain in stability in proportion to their mean thickness: so that, although the 8-inch model had exceeded the 6-inch model, and the latter had exceeded the 4-inch model, in proportional stability, the 20-inch model did not exceed the 12-inch model, nor did it even exceed the 18-inch model in proportional stability.*

After a few trials with the 20-inch model, the cause of this

* As a proof of the above irregularity, I shall remark, that, in our various sloping models, having an exterior slope of one fifth, when successively backed with shingle, so as to represent counterscarp revetments, the 4-inch model lost about four fifths of its original stability; the 6-inch model lost about one third of its original stability; the 8-inch model lost about one

irregularity was discovered; for we observed, that before it began to move at top, which had always been the first apparent effect produced by the action of the scale and weights upon our original small models, this large one would usually slide forwards, more or less, upon its base; which movement necessarily produced a proportional change in the quantity of the supported mass of shingle; so that, in the act of oversetting, the model was exposed to a variable and uncertain pressure of that material, not to a nearly uniform one, as appeared to have been the case, in the experiments tried with the smaller models.

Now as actual revetments cannot possibly slide forwards, without falling, unless the foundation is exceedingly bad, in which case due precautions either are, or at least always ought to be, taken to prevent this movement; it appeared to me, after proceeding so far, that our experiments with shingle would not be conclusive, unless similar precautions were taken to prevent all such of our models, as had that tendency, from sliding upon their base.

For this reason, I caused the whole of the experiments, that had been made with our three large models, to be tried over again, previously nailing down a thin wooden batten, resembling a common flat ruler, upon the plane on which they stood. The section of the above batten was nearly in the form of a wedge, the edge of which came in contact with the front of the base of the sup-

tenth of its original stability; but the 10-inch model lost no stability. So far our experiments appeared to take a regular course, and from these data, it was reasonable to expect, that the 12 and 20-inch models would have gained stability by being used as counterscarp revetments, instead of which the average stability, even of the latter, on being backed with shingle to the proper height, was less, by about one twentieth part, than its average stability before any shingle was applied. A similar irregularity was observable, on using the several countersloping models of the same dimensions, in a similar manner.

posed revêtment, and was of such inconsiderable thickness, that, whilst it prevented the model from sliding as required, it did not diminish the height of it above one eighth part of an inch. When this was done, we found, that the results of the new experiments tried with our large models were no longer irregular and unsatisfactory as before.

Afterwards, I caused such of the smaller models, as had either a slope, or a counterslope of one fifth, also to be tried a second time with shingle, using the same precaution which has just been described, to prevent them from sliding; for, although we had not actually observed any movement of that nature, in the course of our former experiments, I conceived it possible, that it might have taken place in a small degree, and yet eluded our notice; particularly as our attention had not been at all directed to ascertain this point, for we did not apprehend, on commencing our course of experiments, that any irregularity was likely to arise from it. But what is remarkable, on using the battens, in front of the smaller models, instead of causing a greater uniformity in the results, a contrary effect was produced. For in all our small models, whose mean thickness was less than one fourth of their height, when tried as partial scarp revetments, without counterforts, with the shingle raised 30 or 60 inches above the top of each, the results of these new experiments were more capricious even than the former ones, since, in some cases, the same model would appear to have considerable stability; in others, little or none. But when used as counterscarp revetments, without counterforts, the results were always sufficiently regular and satisfactory, not only in the larger models, but also in such of the smaller ones, whose mean thickness was not less than one fifth of their height. Below that proportion great irregularity was observable in the stability of our small models, even when used as counterscarp revetments, without any shingle being applied higher than the top of them. For the irregularities that have been stated, as well as for

others, in the new course of experiments, which in some cases may appear very extraordinary, I shall not attempt to account. It may be observed, however, that I have had them in view, in afterwards framing the general rules for the dimensions of scarp and counterscarp revetments, towards the conclusion of this chapter, in which I might have recommended rather thinner profiles than I have actually done, had the results of those experiments, that were tried with the small models, proved less capricious and contradictory.*

The new course of experiments with shingle, which was conducted in such a manner that the models could not possibly slide forwards upon their base, shall now be laid before my readers, in the same clear and compendious form of tables, which has been already adopted. Thus, having a complete and faithful account of the whole process before him, an intelligent reader may, from thence, draw his own conclusions as to the proper form and dimensions of a revetment for any given purpose, if he should not be inclined to adopt the rules deduced by me from the same experiments.

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* As our experiments, tried with the same models and under the same circumstances, often yielded discordant results;—if any other person were hereafter to undertake a similar course of experiments with shingle, it is not to be expected that these should exactly coincide either with each other, or with those that are recorded in this book. But it may be remarked, that if a certain mean thickness is given to a model of any description, its stability, when loaded with shingle, will always bear a considerable proportion to its original stability without shingle; so that, for example, although the results of various trials may widely differ amongst themselves, yet in none of them shall the stability with shingle be less than three fourths or two thirds of the original stability. When such is the case in any model, it appears to me sufficiently to prove, that if the same proportional mean thickness is given to an actual revetment, it will, by the addition of counterforts, have ample stability as a retaining wall, whether for civil or military purposes.

TABLE VIII.

Models battened in front.	Without Shingle. The Revetment's Height.	Mean Thickness.	Weight.	Stability in various Trials.	With Shingle. Height of Shingle.	Berm = Mean Thickness.	Stability in Trials, 1st.	2d.	3d.	4th.	5th.	No. of the Experiment.
Rectangular.	26	4	182	11	-14	...	0	.	..	..	.	219
				12½	-6	...	0	.	..	..	..	220
				12½	..	...	0	0	0	..	..	221
Sloping at ⅕.	26	4	182	24½	..	...	5	17	12½	8½	10½	222
				24½	6	No	0	0	0	..	..	223
				24½	7	No	0	..	..	..	..	224
				23	9	No	0	..	..	..	..	225
				26	6	Yes	0	..	..	..	..	226
				23	7	Yes	0	..	..	..	..	227
				25	8	Yes	0	.	..	..	..	228
				24½	9	Yes	0	.	..	..	..	229
Leaning at ⅕.	26	4	182	24	-2	...	0	0	..	..	..	230
				25	..	...	0	15½	16½	16½	..	231
				26½	30	No	0	0	..	..	..	232
				26½	30	Yes	6½	4½	5½	..	..	233
				26½	48	Yes	0	0	..	..	..	234
Countersloping ¼.	26	4	182	13½	-8	...	0	..	..	..	..	235
				13½	-6	...	0	0	..	..	..	236
				15½	..	...	7½	13½	11½	..	..	237
				16½	6	No	0	0	..	..	..	238
				15½	9	Yes	0	..	..	..	..	239
				15½	10	Yes	0	..	..	..	..	240
Sloping at ⅕.	26	5⅓	236½	41	..	..	35	30	33	..	..	241
				42	30	No	0	12½	13½	11½	0	242
				41	30	Yes	16½	19½	15	23½	16	243
				43	60	No	10½	10½	10½	..	..	244
				41	60	Yes	15½	16½	17½	..	..	245
Countersloping ⅕.	26	5⅓	236½	23½	..	...	26½	33½	36½	..	..	246
				23½	15	No	0	..	..	..	..	247
				26	24	No	0	..	..	..	..	248
				26	30	No	13½	12½	13½	0	..	249
				23½	30	Yes	30½	18½	30½	..	..	250
				22½	60	No	18½	20½	20½	..	..	251
				21½	60	Yes	44½	20½	24½	23½	..	252

TABLE IX.

Models battened in front.	Without Shingle. The Revetment's Height.	Mean Thickness.	Weight.	Stability in various Trials.	With Shingle. Height of Shingle.	Berm = Mean Thickness.	Stability in Trials. 1st.	2d.	3d.	4th.	5th.	No. of the Experiment.
				28		..	10	2	7	$4\frac{1}{2}$	$4\frac{1}{2}$	253
				27	18	No	0	..	..	..	..	254
				28	21	No	0	..	..	..	..	255
Rectangular.	26	6	273	25	9	Yes	0	0	..	..	..	256
				26	15	Yes	0	..	..	..	..	257
				28	30	Yes	$2\frac{1}{2}$	$2\frac{1}{2}$	..	..	..	258
				28	30	Yes	0	0	..	..	..	259
				49	..	...	43	38	..	..	..	260
				48	30	No	29	30	32	..	..	261
Sloping at $\frac{1}{5}$.	26	6	273	48	30	Yes	33	43	31	..	..	262
				49	60	No	41	41	45	..	..	263
				50	60	Yes	41	41	54	..	..	264
				$55\frac{1}{2}$	.	...	$39\frac{1}{2}$	$40\frac{1}{2}$	$42\frac{1}{2}$	..	..	265
				$53\frac{1}{2}$	30	No	$36\frac{1}{2}$	$42\frac{1}{2}$	$39\frac{1}{2}$	..	..	266
Leaning at $\frac{1}{5}$.	26	6	273	$57\frac{1}{2}$	30	Yes	$27\frac{1}{2}$	$28\frac{1}{2}$	$25\frac{1}{2}$	..	..	267
				$56\frac{1}{2}$	60	No	$16\frac{1}{2}$	$38\frac{1}{2}$	$44\frac{1}{2}$	47	..	268
				$60\frac{1}{2}$	60	Yes	$57\frac{1}{2}$	$46\frac{1}{2}$	47	47	..	269
				28	..	...	31	34	40	$35\frac{1}{2}$	34	270
				30	30	No	14	14	10	$36\frac{1}{2}$	$33\frac{1}{2}$	271
Countersloping $\frac{1}{5}$.	26	6	273	31	30	Yes	0	0	$38\frac{1}{2}$	$14\frac{1}{2}$	$31\frac{1}{2}$	272
				$31\frac{1}{2}$	60	No	13	18	25	$9\frac{1}{2}$	$8\frac{1}{4}$	273
				29	60	Yes	$16\frac{1}{2}$	$32\frac{1}{2}$	$32\frac{1}{2}$	10	20	274
				58	..	...	46	49	47	..	..	275
				59	30	No	37	31	25	..	..	276
Sloping at $\frac{1}{5}$.	26	$6\frac{1}{2}$	$295\frac{1}{4}$	60	30	Yes	46	39	39	..	..	277
				59	60	No	37	31	27	..	..	278
				61	60	Yes	44	38	36	..	..	279
				36	..	...	56	53	45	35	..	280
				35	30	No	39	28	27	45	35	281
Countersloping $\frac{1}{5}$.	26	$6\frac{1}{2}$	$295\frac{1}{4}$	37	30	Yes	31	47	38	37	44	282
				38	60	No	58	42	39	$16\frac{1}{2}$	$27\frac{1}{2}$	283
				39	60	Yes	42	13	19	31	$39\frac{1}{2}$	284
				86	..	...	68	69	70	..	..	285
				79	30	No	63	57	59	..	..	286
Sloping at $\frac{1}{5}$.	26	$7\frac{1}{10}$	$335\frac{3}{16}$	78	30	Yes	66	62	64	..	..	287
				76	60	No	60	57	57	..	..	288
				78	60	Yes	64	65	66	..	..	289

TABLE X.

Models battened in front.	Without Shingle. The Revetment's Height.	Mean Thickness.	Weight.	Stability in various Trials.	With Shingle. Height of Shingle.	Berm = Mean Thickness.	Stability in Trials, 1st.	2d.	3d	No. of the Experiment.
Countersloping ⅕.	26	$7\frac{11}{30}$	$335\frac{3}{16}$	41½	..	..	89	87	86	200
				42½	30	No	68	62	67	201
				45	30	Yes	72	78	73	202
				43	60	No	87	74½	81½	203
				43	60	Yes	91	85½	89½	204
Sloping at ⅕.	26	8	364	96	..	.	93	89½	99½	205
				99	30	No	60	71½	72	206
				94	30	Yes	72	77	74	207
				93	60	No	82	68	74	208
				97	60	Yes	103	89	91	209
Leaning at ⅕.	26	8	364	90	.	..	69	71	77	300
				87	30	No	65	57	61	301
				81	30	Yes	78	63	59	302
				86	60	No	68	67	68	303
				82	60	Yes	94	78	70	304
Countersloping ⅕.	26	8	364	53		...	89½	90½	100	305
				54½	30	No	117½	83½	85½	306
				58	30	Yes	96½	94	101	307
				59	60	No	101	118½	111½	308
				57½	60	Yes	140	[illegible]	138	309
Sloping at ⅕.	26	10	455	136	.	...	136	136	..	310
				138	30	No	132	125	132	311
				125	30	Yes	140	125	140	312
				134	60	No	133	125	129	313
				138	60	Yes	125	129	...	314
Countersloping ⅕.	26	10	455	87	.	...	160	164	164	315
				94	30	No	181	181	181	316
				90	30	Yes	163	160	160	317
				88	60	No	174	181	174	318
				92	60	Yes	157	178	180	319
Sloping at ⅕.	26	12	546	182	.	...	194	195	188	320
				181	30	No	188	181	187	321
				181	30	Yes	181	181	...	322
				181	60	No	181	195	208	323
				177	60	Yes	184	182	...	324

TABLE XI.

Models battened in front.	Without Shingle.				With Shingle.					No. of the Experiment.
	The Revetment's				Height of Shingle.	Berm = Mean Thickness.	Stability in Trials,			
	Height.	Mean Thickness.	Weight.	Stability in various Trials.			1st.	2d.	3d.	
Countersloping ¼.	26	12	546	129	.	. . .	266	321	265	325
				152	30	No	258	287	237	326
				132	30	Yes	228	322	286	327
				151	60	No	279	257	351	328
				126	60	Yes	355	293	349	329
Sloping at ¼.	26	20	910	441	. .	. .	401	510	475	330
				417	30	No	615	629	657	331
				443	30	Yes	482	463	476	332
				457	60	No	657	637	671	333
				444	60	Yes	469	482	482	334
Countersloping ½.	26	20	910	363	.	. . .	550	517	546	335
				370	30	No	727	755	738	336
				367	30	Yes	685	573	629	337
				349	60	No	734	629	671	338
				379	60	Yes	615	573	570	339
Sloping at ⅕.	52	8	728	120	. .	. . .	45	45	. . .	340
				118	24	No	0	0	. . .	341
				119	30	Yes	15½	14½	13½	342
				118	35	Yes	0	. . .	. . .	343
				118	36	Yes	0	. . .	. . .	344
Countersloping ⅕.	52	8	728	62	.	. . .	0	0	0	345
Sloping at ⅕.	52	10⅔	946½	161	. .	. . .	103	99	94	346
				163	30	No	34	31	37	347
				165	30	Yes	66	73	70	348
				164	60	No	56	57	55	349
				164	60	Yes	76	82	76	350
Countersloping ⅕.	52	10⅔	946½	96	.	. . .	64	61	67	351
				94	30	No	28½	36½	42½	352
				96	30	Yes	79½	74½	65½	353
				95	60	No	45½	80½	83½	354
				95	60	Yes	83½	84½	84½	355

TABLE XII.

Models battened in front.	Without Shingle.				With Shingle.					No. of the Experiment.
	The Revetment's				Height of Shingle.	Berm = Mean Thickness.	Stability in Trials,			
	Height.	Mean Thickness.	Weight.	Stability in various Trials.			1st.	2d.	3d.	
Rectangular.	52	12	1092	122	..	...	17½	20½	18½	356
				123	10	No	0	0	...	357
				122	12	No	0	...	...	358
				124	21	Yes	0	0	...	359
				123	27	Yes	0	...	...	360
Leaning at ⅕.	52	12	1092	205	...	...	170	171	188	361
				209	30	No	96	93	125	362
				227	30	Yes	101	127	136	363
				206	60	No	69	96	115	364
				234	60	Yes	106	101	118	365
Sloping at ⅓.	52	13	1183	259	...	...	210	182	184	366
				248	30	No	151	159	125	367
				256	30	Yes	176	160	178	368
				262	60	No	121	117	125	369
				269	60	Yes	202	199	199	370
Countersloping ⅓.	52	13	1183	168	..	...	160	168	185	371
				168	30	No	78	101	107	372
				157	30	Yes	148	160	125	373
				167	60	No	150	113	139	374
				166	60	Yes	181	165	138	375
Sloping at ⅓.	104	29 7/13	5363	1263	..	...	1155	1036	1218	376
				1263	52	No	1056	1016	...	377
				1280	52	Yes	1183	1064	1176	378
				1345	104	No	1151	1070	1056	379
				1325	104	Yes	1294	1280	1322	380
Countersloping ⅓.	104	29 7/13	5363	734	..	...	1202	1235	1196	381
				730	52	No	1068	1019	1075	382
				774	52	Yes	1182	1189	1042	383
				760	104	No	1003	956	1045	384
				756	104	Yes	1107	1070	1098	385

TABLE XIII.

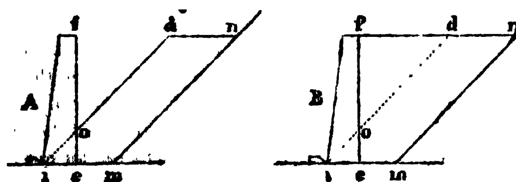
Models battened in front.	Without Shingle.							With Shingle.					No. of the Experiments.
	Revet^t.		Counter^{ft}.			Total.				Stability in Trials,			
	Height.	Mean Thickness.	Length.	Width.	Cent. Interval.	Weight.	Stability in various Trials.	Height of Shingle.	Berm = Mean Thicks.	1st.	2d.	3d.	
							60	. .	. . .	73	73	71	386
							58	30	No	59	58	61	387
Sloping at ⅕.	26	5⅕	4	4½	18	282	59	30	Yes	59	62	60	388
							60	60	No	60	58	69	389
							57	60	Yes	71	68	70	390
							34	.	. . .	62	73	68	391
							36	30	No	54	49	51	392
Countersloping ⅕.	26	5⅕	4	4½	18	282	35	30	Yes	65	60	62	393
							34	60	No	60	66	63	394
							35	60	Yes	68	61	65	395
							85	. .	. . .	115	116	116	396
							86	30	No	117	123	119	397
Sloping at ⅕.	26	6½	5⅕	4½	18	354⅞	85	30	Yes	118	119	123	398
							85	60	No	126	136	147	399
							86	60	Yes	118	126	123	400
							51	. .	. . .	110	117	121	401
							52	30	No	129	137	134	402
Countersloping ⅕.	26	6¼	5⅕	4½	18	354⅞	53	30	Yes	127	132	126	403
							52	60	No	156	149	145	404
							52	60	Yes	115	125	119	405
							349	. .	. . .	579	584	576	406
							349	30	No	576	594	584	407
Sloping at ⅕.	52	13	10⅖	4½	18	1419½	347	30	Yes	587	573	580	408
							348	60	No	569	547	559	409
							349	60	Yes	555	559	547	410
							230	. .	. . .	612	607	601	411
							229	30	No	622	616	619	412
Countersloping ⅕.	52	13	10⅖	4½	18	1419½	230	30	Yes	610	589	604	413
							230	60	No	688	689	694	414
							230	60	Yes	620	617	622	415

The results of the experiments contained in the above tables, fully prove the correctness of the new principles laid down by me, upon the theory of revetments, as far as regards the general action of the total mass of loose earth, supported by any profile. But with respect to the precise effect, produced singly by either of the component parts, such as the upper and lower portions, into which the said mass may be divided; as that may still appear a matter of doubt, I shall now proceed to state the nature of some additional experiments, which were tried for the purpose of investigating this part of the subject.

We first took the 4-inch model, sloping at one fifth, and 26 inches high, and backed it with shingle, in the manner represented in the annexed figure, A; heaping up that material, in rear, to a level, equal to the height of the top, f, of the model, but taking care to raise it, in front, no higher than the point o, which is only 6 inches above the base, i e.

By this arrangement, the dotted line, i o, produced, was made to coincide with the natural slope, o d, of the upper portion of the supported shingle, so that the shingle pressing upon our supposed revetment, A, in this peculiar case, exactly agrees with what would have been the lower portion only of the total mass of shingle, acting upon the same, if it had been backed with that material, as a counterscarp revetment, in the usual manner.

On trying the average stability of our 4-inch model, thus partially loaded with the mass of shingle, e o d n m, acting upon



the lower part of it only (*See fig.* A), it proved to be 31½ lbs.

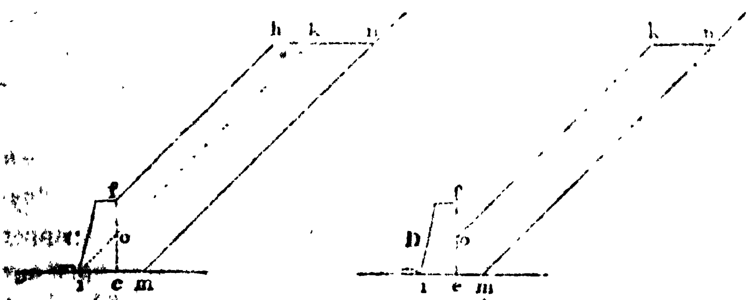
which exceeds what had been the original average stability of the same model, before any shingle was applied to it, by 7 lbs.

Afterwards, by increasing the quantity of shingle, pressing upon the same 4-inch model, by backing it to the continued horizontal level, f d n, so as to represent a counterscarp revetment, as shown in figure B, we found that its average stability became equal to 10½ lbs. only. Now, this diminution of stability, in our present experiment, when compared with the former one, must necessarily be ascribed solely to the additional triangular mass of shingle, o f d, which acts upon B, but not upon A, and which constitutes the only difference between these two profiles. Hence, on dividing the mass of shingle, supported by the 4-inch model, considered as a counterscarp revetment, into two portions, an upper and a lower one, in the manner before explained, the first of the above experiments may be allowed to prove, that the lower portion, e o d n m, tends solely to stabilitate the supposed revetment, whilst the results of the first and second experiments, combined, prove, in a manner no less satisfactory, that the upper portion, o f d, of the supported mass, tends to weaken the supposed revetment. And the diminution of stability, occasioned by the said portion, o f d, acting upon our 4-inch model, in experiment, B, may, of course, be estimated, at 21 lbs.; this being equal to the difference between the two numbers, 10½ and 31½, which represent respectively the stability of profiles, B and A.*

* Another mode occurred of endeavouring to ascertain the action of the upper portion, o f d, by experiment, which was to place a sloping board, in the position, o d, to bound the shingle in rear, and thus to apply a mass of shingle, o f d, to the upper part, o f, of the back of the supposed revetment only, leaving the space, e o d n m, behind and below the board, o d, entirely vacant. But, on further consideration, we rejected the mode, now alluded to, as being less likely to prove accurate than the former; because the interposition of a solid plane of woodwork, such as the board, o d, would evidently prevent the mass of shingle, o f d, from exerting its natural action, in any direction, falling within the lower part, e o, of the back of

We afterwards tried similar experiments, successively, with the other sloping models, of the same height and exterior slope, but of greater mean thickness, and raising the shingle above them to a greater height; from all of which we obtained the same general result, namely, that the lower portion of the supported mass of loose earth, acting upon a revetment, does in all cases add stability to it, whilst the upper portion of the supported mass, when such there is, in any profile, appears always to weaken it, in a certain degree. But to relate the whole of these trials would be superfluous. Two more of them only shall therefore be stated, which will suffice for the purpose of illustration.

On trying the 6-inch model sloping at one fifth, and 26 inches high, when backed with the mass of shingle, e f h n m, as shown in figure C, heaped to the height of 60 inches above the top, f, of the model, with a berm equal to the thickness at top of the supposed masonry; the average stability of the profile proved to be 39 lbs.; but when the same model was backed with the lower portion, e o k n m, of the said mass only, as shewn in figure D, its average stability proved to be 57 lbs. Consequently the diminution of stability, occasioned by the upper portion, o f h k, of the supported



the supposed revetment; whereas, in real practice, no such obstacle is ever used, so that the upper part of the supported mass, pressing upon an actual revetment, is left free to exert its natural action in all possible directions, favourable, as well as unfavourable, to stability.

earth, acting upon our 6-inch model, in the former experiment, C, may be estimated at 18 lbs.; this being equal to the difference between the numbers, 57 and 39, which represent respectively the average stability of profiles, D and C.

In like manner, on afterwards trying the 12-inch sloping model, of the same slope and height, under the circumstances last described, its average stability as a partial scarp revetment, when backed with shingle, in the manner shown in figure C, proved to be 181 lbs.; whilst its average stability, when backed with the lower portion of the same mass only, as shown in figure, D, proved equal to 185 lbs.; so that the difference, 4 lbs., may be assumed as the average value of the weakening power of the upper portion of the supported earth, acting upon the 12-inch model, in the former case.

Now, as the original average stability of each of the above three profiles, namely, the 4-inch, the 6-inch, and the 12-inch sloping models, was equal respectively to 24½ lbs. 47 lbs. and 181 lbs. before any shingle was used, and as the average value of the weakening power of the superior portion of the supported mass, acting upon each, when backed with shingle, the first in the manner represented in figure B, the two others in the manner represented in figure C, has just been shown to be equal respectively to 21 lbs. 18 lbs. and 4 lbs.; hence it follows, that in the 4-inch model, the weakening power of the upper portion of the supported mass was equal to about $\frac{7}{8}$ths of the original stability; in the 6-inch model it was equal to about $\frac{3}{8}$ths of the original stability; but in the 12-inch model, it was equal to about $\frac{1}{45}$th part only of the original stability.

Upon the whole, therefore, it appears, that although the upper portion of the supported mass of loose earth, pressing upon any revetment, always tends to weaken the profile more or less; yet that the said weakening power, which in profiles, sloping at one fifth, whose mean thickness is less than three thirteenths of their height, is very considerable, gradually diminishes, in proportion as any addition is made to the mean thickness: so that in similar

profiles, whose mean thickness is equal to six thirteenths of the height, the said weakening power becomes altogether inconsiderable and insignificant, not exceeding on an average about one forty-fifth part of the original stability. And yet, even in cases in which the weakening power of the upper portion of the supported mass is so trifling, as has just been stated, the actual weight, wherewith it presses upon the revetment, may be very considerable, as was proved by the last-mentioned experiment, tried with the 12-inch model, in which the weight of the upper portion only of the supported mass of shingle was more than double the weight of the supposed revetment, as may easily be ascertained by calculation.

In reflecting further upon the same experiments, now under discussion, it will also be evident, that by increasing the mean thickness of a sloping revetment to more than six thirteenths of the height, the weakening power of the upper portion of the supported mass of loose earth will also be diminished to less than one forty-fifth part of the original stability; and thus, by successively increasing the mean thickness of masonry, more and more, other particulars remaining the same, the weakening power of the upper portion may be more and more diminished, until at length it shall become null;—an effect, which in sloping revetments, without counterforts, may be expected to take place, when the base of the masonry is made equal to the height, or nearly so.*

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* The effect of the weakening power of the upper portion of the supported mass of loose earth has been proved to be very inconsiderable, in a revetment sloping at one fifth, even when the base is not much more than half the height, as is the case in the 12-inch model. But when the base is made equal to the height, in any sloping profile, the superior portion of the supported mass, even although the loosest possible material should be used, will be made almost entirely to disappear, and consequently its effect must be null, or nearly so, according to the circumstances before taken into consideration, in treating of the first case of revetments. (*See page* 551.) In the 20-inch sloping model, however, whose base was almost equal to nine tenths of its height, we found, by experiments tried also

After concluding our experiments with shingle, our next object was to ascertain the effect, produced upon the same models, by the pressure of common earth. On trying our sloping and rectangular profiles, as counterscarp revetments, by backing them with soil of a middling tenacity, consisting of sand mixed with clay, to the level of the top of each, we found that no increase or diminution of stability whatever was produced; for, at the small height of 26 inches, the earth, although loosely thrown up, did not exert any oblique or lateral pressure; but almost always stood perpendicularly, in the form given to it by the back of these models, for some time after the latter were overset by means of the scale and weights. We were therefore obliged to desist from making any further experiments with common earth; for, unless we had used very unwieldy models of at least three or four times the height above mentioned, in which case the earth would no doubt have had a certain pressure, it appeared sufficiently evident, that no useful conclusion could be expected.

We next tried the effect produced upon our models by backing them with earth of the same quality, that has just been described, but well rammed, so that it became capable of standing perpendicularly, or even in an over-hanging form, for a permanency, and acquired a weight of about 99 lbs. per cubic foot. Great care was taken, in the experiments, now alluded to, that the degree of tenacity, communicated by the process of ramming, should, in all cases, be as nearly equal as possible.

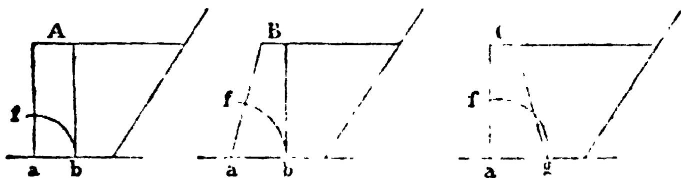
On trying the rectangular model, whose height was 26 inches,

under the circumstances represented in figures, C and D, that the upper portion of the supported shingle still appeared to exert some degree of weakening power upon the profile, but so exceedingly inconsiderable, that we could not reduce the results of our various trials, which were in some cases contradictory, to any satisfactory average conclusion.

and thickness 8 inches, as a counterscarp revetment, with rammed earth, as shown in the annexed figure A, its average stability proved to be 60 lbs.; and its original average stability without earth, being 47 lbs.; it follows, that the additional stability gained in this profile, by reason of the rammed earth, may be estimated at 13 lbs.

The stability of the common sloping model, whose height was 26 inches, mean thickness 8 inches, and slope ⅛th, was 85 lbs. without earth; but on backing it with rammed earth, to represent a counterscarp revetment, as shown in figure B, its stability proved to be 97 lbs.; so that the increase of stability, in this profile, produced by means of the rammed earth, appeared to be 12 lbs.

The stability of the countersloping model, whose height was 26 inches, mean thickness 8 inches, and slope ⅛, was 51 lbs. without earth; but on backing it with rammed earth, to represent a counterscarp revetment, as shown in figure C, its stability proved to be 131 lbs.; so that the increase of stability, in this profile, produced by means of the rammed earth, appeared to be no less than 78 lbs.



The reason of the superiority of strength, which it was thus proved by experiment, that the countersloping profile, C, possesses over the rectangular and sloping profiles, A and B, of the same height and mean thickness, when they are all backed with earth of a tenacious quality, will be sufficiently obvious, on considering the nature of the movement, which must be performed by each of these respective models, or supposed revetments, in falling. When the countersloping model, C, for example, oversets, the heel of it, g, describes an arc, g f, upon the center, a, which cuts into the mass of rammed earth behind it, so that the fall of the model cannot be effected, without violently separating or tearing asunder

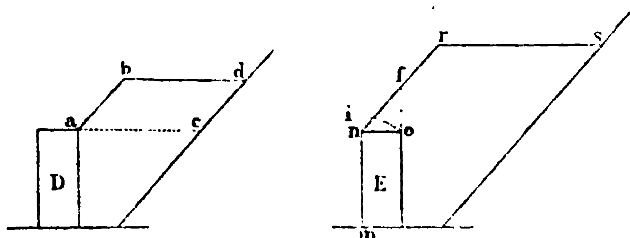
a certain portion of the said mass, from the remainder of it; and accordingly, it may easily be conceived, that the tenacity of the earth, when considerable, must necessarily oppose a proportional resistance to the supposed movement.* The increase of stability, added to our countersloping model, in consequence of the above resistance, may not unaptly be compared to the security, afforded by good holding ground, to a ship at anchor.

With respect to the rectangular and sloping models, A and B, on the contrary, it is evident, that when they fall, the heel of each, b, describes an arc, b f, from the center, a, which does not cut into the mass of earth behind, nor does any other part whatever of these models cut into the said mass, in oversetting. Consequently as no portion of the rammed earth is to be torn asunder, whilst this movement takes place; it is evident, that the additional stability, which appears by the experiments to have been gained in profiles, A and B, when used as counterscarp revetments, must be ascribed solely to the friction arising from the rough surfaces of the back of each model, and of the earth in contact with it, being made to adhere together, in a certain degree, by the process of ramming.

We further found, in using rammed earth, that whenever a berm was left, equal to the thickness at top of the model, no difference whatever was produced in the stability of our profiles, by raising the earth to any given height, above the supposed revetment. Thus, for example, the stability of the rectangular profile, in the annexed

* A similar effect must take place, to a certain degree, even in shingle or loose sand; for, in the fall of any countersloping revetment, backed with these materials, the heel of it must necessarily force upwards some portion of the supported mass, the weight of which cannot fail to oppose a certain resistance to the supposed movement. This consideration accounts for the additional stability often communicated to this kind of profile, in our experiments with shingle, in cases, in which we found, that the sloping model of the same height and mean thickness lost stability, when backed with the same material and under the same circumstances.

figure, D, proved to be, in all cases, precisely the same, whether it was backed with rammed earth to the height, a c, only, so as to represent a counterscarp revetment, or whether it was backed with the same substance to any much greater height, such as b d.

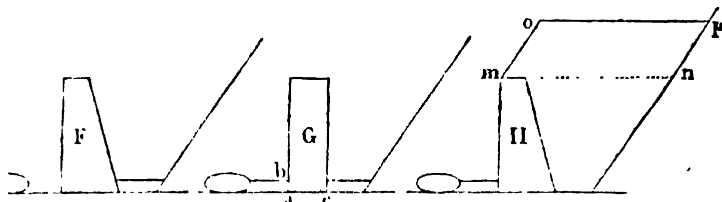


In figure E, on the contrary, in which the earth is supposed to be raised to a certain height above the top of the model, without any berm, it will be evident, that if the model is overset in the usual manner, the back of the top of it, o, will from the centre, m, describe the arc, o i, cutting into the superincumbent triangular mass of earth, n o f, so that a certain portion of this mass must necessarily be separated from the remainder of the earth, during the fall of the supposed revetment. Accordingly, we found, that the stability of the rectangular model, whose height was 26 inches and thickness 8 inches, was equal to 159 lbs. when used as a partial revetment for rammed earth without a berm, as shown in figure E, although its original stability before the earth was applied to it had only been 47 lbs. We first tried this experiment with the earth raised to the height of 8 inches only, above the top of the model, that is to say to the level of the point, f, and such was the result obtained. On raising it afterwards to a much greater height, such as r s, no increase of stability whatever was produced, because after tearing off the greater part of the right angled triangle, n o f, which the model usually does in oversetting,* the

* Contrary to our expectations, we found that the back of the mass of rammed earth, torn off by the top of any of our models, did, in general, more nearly correspond with the line, o f, than with the curve, o i.

remainder of the mass of rammed earth behind and above the line, o f, remained always perfectly firm and without action, no matter how great the height of it might have been.

Having sufficiently ascertained the action of rammed earth upon our models, under the various circumstances that have been described, we next tried them with foundations of two inches of rammed earth in front of them; first, with the rammed earth in rear also raised no higher than 2 inches above the wooden plane on which the models stood, in the manner shown in the annexed figures, F and G; afterwards as revetments, in the manner shown in figure H, with the rammed earth in rear, raised sometimes to the



level, m n, to represent a counterscarp revetment, and sometimes to a higher level, o p, to represent a partial scarp revetment without a berm. The rammed earth, forming the small foundations, was secured in front, by applying sand-bags, as shown in the figures, to prevent it from being forced forwards.

These small foundations gave great additional stability to all our models, not excepting even the rectangular one represented in figure G; for when this model falls, it is evident, that the heel of it, c, describes an arc, not from the point, a, as a center, as was the case in our former figures, in which the same profile was concerned, but from the point, b, with the radius, b c, which must necessarily cut into the mass of rammed earth, in rear of it. Accordingly, we found, by experiment, that the rectangular model, whose height was 26 inches and thickness 8 inches, acquired an average stability of 85 lbs. in consequence of the two inches of rammed earth being applied in front and rear of it, as

shown in figure G, although its original average stability had only been 47 lbs.

The small model countersloping at one-fifth, whose height was 26 inches, and mean thickness 4 inches, acquired a stability of 84 lbs.; by having a foundation of two inches of rammed earth, as shown in figure F, although its original stability had only been 12½ lbs.

The medium countersloping model, of the same height and counterslope, but whose mean thickness was 6 inches, acquired a stability of 99 lbs. in consequence of a similar foundation, although its original stability had only been 29 lbs.

And the large countersloping model, of the same height and counterslope as the former, but whose mean thickness was 8 inches, acquired a stability of 154 lbs. in consequence of a similar foundation, although its original stability had only been 51 lbs.*

Here it may be remarked, that the above experiments prove the very great advantage, which walls, built upon soil of a tenacious quality, must derive from having foundations of a certain depth. With respect to offsets at the bottom of walls, it is sufficiently obvious, that, by augmenting the base, they must proportionally increase the stability of the masonry. In inclosing walls, such as those of gentlemen's parks, powder magazines, dockyards, &c. the thickness of which, as compared with their height, is inconsiderable, offsets on both sides are of the most indispensable necessity; and, in all cases, several successive small ones should be used, in preference to two or three wider ones. In revetments, properly so styled, offsets, near the foundation, may be omitted with less prejudice to the strength of the profile; but still they are

* It is proper to observe, that in our previous experiments with shingle, we also tried some of our models with and without foundations of two inches of that material, but in using so loose a substance, we found, that these small foundations made little or no difference as to the stability.

useful, whether allowed in front or in rear, as they cannot fail to increase the stabilitating power of the supported mass of earth.*

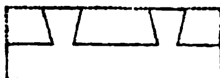
To return to our experiments with rammed earth; our next object was to ascertain the effect, produced by this material, upon revetments with counterforts. We first tried the common rectangular counterforts which we had before used with shingle; but we soon found that our former mode of fastening them was, in this case, insufficient; for the sides of the counterforts were so firmly grasped by the earth, that they remained immovable, in an upright position, whilst the supposed revetment, that had been nailed to them, was torn down by the action of the scale and weights. We, therefore, united the revetments and counterforts together by iron bolts of a proper strength, after which we proceeded with our experiments, without further difficulty.† Finding, in the course of three experiments, that the model, in oversetting, generally pulled down with it the whole of the three contiguous

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* In former parts of this chapter, in treating of the action of loose earth upon a revetment, I judged it expedient, for the sake of clearness, to leave the foundation of the wall unnoticed, and therefore, in the various explanatory figures (*such as that in page* 542) I estimated the lower portion, a g f c, of the supported mass of earth, as being bounded in rear by a line drawn from the back (a) of the base (a d) of the revetment. But it will be evident, that as the foundation also must have its effect, the true position of the boundary line of the lower portion ought to be in rear of a c, as the said line should be drawn, not from the back of the base (a), but from that point immediately below it, which represents the back of the foundation. Hence, the stabilitating power of the supported earth of each profile, commented upon in the text, is, in reality, greater than I have there thought it expedient to suppose.

† It is proper to remark, that we were obliged also to increase the strength of our ropes and pullies, and to suspend the latter from small gins, or triangles, erected for the purpose, as the apparatus, before described, broke down, under the greater weights, which it was necessary to use, in our experiments with rammed earth. During the process of ramming, strong temporary props were applied in front of all our models, to prevent the force in rear from throwing them out of their proper position.

masses of earth, bounded in rear by a vertical plane, supposed to coincide with the back of our two counterforts, it appeared probable, that this effect, which, of course, must add greatly to the strength of a profile, in tenacious soil, might either be much increased, or, at least, rendered more invariably certain, without any possible risk of failure, by constructing DOVETAILED COUNTERFORTS, wider at the tail than at the root, the outline of the plan of which is as follows:*



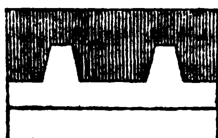
I accordingly caused some of our counterforts to be fitted up in this manner. Part of them, which were 4 inches long, were made 5¾ inches wide at the tail, and 4¼ inches wide at the root, their mean width being 5 inches: the remainder, which were 6 inches long, were made 6 inches wide at the tail, and 4½ inches wide at the root, their mean thickness being 5¼ inches · and the results of the experiments, made with these dovetailed counterforts, in rammed earth, answered our expectations, they proving generally to communicate rather more stability to the profile than the rectangular ones, but not however in any very great degree; and the results, indeed, being sometimes rather contradictory, as will afterwards be seen.

As it also appeared probable, that the great additional strength which our profiles with counterforts appeared to derive, in consequence of the cohesion of the rammed earth to the sides of the counterforts, might be much lessened, by using diminished counterforts, like those of Vauban, instead of rectangular ones; we lastly tried diminished counterforts, exactly of the same dimensions as the dovetailed ones, that have been described, but being of

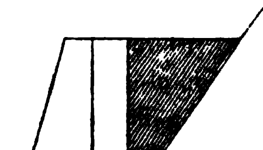
* The dotted lines are added, to show the extent of those masses, which are torn off from the remainder of the rammed earth, and adhere to the revetment and counterforts, in falling.

course reversed, or wider at the root than at the tail. But here the result did not, by any means, agree with our previous ideas; for the stability of this profile far exceeded our expectations, and indeed fell very little short of the former kinds, that have just been noticed; that is, generally speaking, for in some particular trials, it exceeded them both, the results of all our experiments with rammed earth being much less regular than those that were tried with shingle.

As an example of the effect of diminished counterforts; on trying the sloping model 26 inches high, and having a mean thickness of 6 inches, and a slope of one fifth, with two counterforts of the above description attached to it, each 6 inches long, 6 inches wide at the root, and 4½ inches wide at the tail, and placed at central intervals of 18 inches apart, as shown in plan and section, in the annexed figures; its stability, as a counterscarp revetment, when backed with rammed earth, but without any foundation in



PLAN.



SECTION.

front of it (*See the section*) proved to be no less than 305 lbs. although its original stability had only been equal to 86 lbs.*

Now it will be obvious, on a little reflection, and indeed almost

* We tried many more experiments with dovetailed and diminished counterforts, than actually appear in the following tables. I judged it useless to insert the whole of them, as they could only create confusion, for we found, that the difference of stability, between them and rectangular counterforts, was in all cases trifling, and indeed the results often proved contradictory, as was before stated in the text. I conceive that the peculiar irregularity in the results of our experiments with rammed earth, may be ascribed to its having been difficult or rather impossible for the men employed, to communicate an exactly equal degree of tenacity to that substance, by ramming, in various trials.

on a mere inspection of the figures, that the great additional stability, communicated to the profile, which has just been described, in consequence of the rammed earth, must be ascribed solely, as in a case before noticed, to the power of friction; or, in other words, to the cohesion of the rough surfaces of the rammed earth, and those of the supposed revetment and its counterforts, which come in contact with each other: for it must be evident, that in the falling of the model, as soon as the above cohesion is overcome, neither the revetment nor counterforts have to cut into or tear asunder any portion of the rammed earth whatsoever, but on the contrary are immediately disengaged from it: and indeed, in all our experiments with the diminished counterforts, after the models were pulled down by the action of the scale and weights, the rammed earth was left standing, in the firmest manner, with regular grooves, where the counterforts had been, so as to resemble a perfect mould of the back of the woodwork.

I before stated, that on trying the original stability of our various models, before any shingle, &c. was applied in rear of them, they were always observed to move, some time before they actually overset. The same circumstance also invariably occurred, in trying their stability afterwards as revetments, when backed with shingle or rammed earth. In our experiments without counterforts, the weight which produced the first perceptible movement in the sloping and leaning models, generally varied from $\frac{2}{3}$ds to $\frac{3}{4}$ths, of the total oversetting weight, and in some cases it even considerably exceeded the latter proportion;* whereas, in the common countersloping models, used by us, which were plane in rear, the weight necessary for producing the first perceptible movement, varied from very little more than $\frac{1}{2}$ to about $\frac{2}{3}$ds of the total oversetting weight, very seldom indeed exceeding the last named proportion. Having, however, afterwards, for the sake of expe-

* It proved sometimes equal to $\frac{9}{10}$ths of the oversetting weight.

riment, constructed some few countersloping models with offsets in rear, we found, that in all of these, the weight, which was necessary for producing the first perceptible movement, bore fully as great a proportion to the total oversetting weight as in any of the other profiles; and we further found, that each of these countersloping models with offsets, required rather a greater weight to overset it, when backed with rammed earth, than was necessary for oversetting a plane countersloping model of the same height and mean thickness, under similar circumstances; but that when shingle was used, the total weight requisite for oversetting the two kinds of countersloping models, that have just been mentioned, proved, in all cases, to be nearly equal. From these facts, I conceive, that the following inference may be drawn, namely, that no countersloping profile should ever be built without well sized offsets in rear, because although such offsets do not appear to add much to the final stability of the wall, as far as regards its complete downfal; yet it must be allowed, that they may tend very materially to prevent it from moving in a perceptible degree: that is to say, that they will prevent the masonry from bulging, overhanging, or otherwise losing its proper shape, which it is well known that weak or badly constructed walls are apt to do, even when they may not eventually fall down.

Their general nature having already been explained by a few examples, the various experiments made by us with rammed earth *

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* The original mean stability of the several models, before the rammed earth was applied to them, as given in Tables XIV and XV, is generally such as was, when they were tried standing loose, as in the first seven tables. As there is often a considerable difference in the original stability of our various models, which may be observed by comparing the Tables of Experiments, it is right to observe, that in all discordant cases, I consider those trials, that are recorded in Tables VIII, IX, X, XI, XII, and XIII, in which battens were applied in front, as being by far the most accurate; for in conducting these, the slopes and other dimensions, and even the weight of each model, were carefully examined and corrected,

shall now be laid before the reader in the clearer and more convenient form of tables. I shall only previously remark, that the experiments tried with rammed earth, do not appear to me to afford any just grounds for judging of the comparative stability of various profiles; because when the earth of a rampart is of so very tenacious a nature, as to resemble that which was used by us in the said experiments, it can, of course, have no tendency whatever to overset the revetment, let the form of the profile be what it may; but on the contrary it must always communicate some additional stability, by reason of the friction or cohesion that was before treated of. The additional stability, thus communicated, cannot, however, be deemed of any real use to an actual revetment, because it can never be brought to act in opposition to any external force of an unfavourable nature, so that the advantage, now under consideration, if such it can be called, is a very negative one. For this, as well as for another no less important reason, afterwards explained, I have, therefore, paid no attention to the peculiar experiments tried with rammed earth, in framing the rules on revetments, that will be found in a subsequent part of this chapter.*

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when necessary, after every two or three experiments. This precaution had been neglected in our other experiments, in which, therefore, although all the models were very accurately made at first, I conceive, that by the wearing of the woodwork of the base, or otherwise, they may in some degree have lost their proper form, after a certain number of trials.

* It is further to be observed, that the experiments with rammed earth do not appear to afford any satisfactory criterion for judging of the stability of actual revetments, backed with earth of equal tenacity, because on trying models exactly similar in other respects, but of different magnitudes, their respective stability with rammed earth, bore no fixed proportion, at different heights, to the original stability of the same models, without earth. In the experiments with shingle, on the contrary, the results yielded by the largest and smallest models used, always nearly corresponded with each other, whenever the profiles were similar, as will afterwards be explained.

TABLE XIV.

	Description of the Models used, &c.	Without Earth. The Revetment's Height.	Mean Thickness.	Weight.	Mean Stability, standing loose.	With rammed Earth. Height of Earth.	Stability in Trials, 1st.	2d	3d.	No. of the Experiment.
With no Foundations in Front.	Countersloping $\frac{1}{8}$ ..	26	4	182	$12\frac{1}{4}$	..	19	22	26	1
	Sloping at $\frac{1}{6}$				27	..	42	42	53	2
	Countersloping $\frac{1}{5}$ ..				$12\frac{1}{2}$	..	28	51	53	3
	Countersloping $\frac{1}{8}$ ..	26	6	273	$27\frac{1}{2}$	.	49	63	63	4
	Sloping at				51	..	68	62	65	5
	Countersloping $\frac{1}{5}$ ..				29	.	84	105	89	6
	Rectangular	26	8	364	47	.	50	61	70	7
	Do				47	8	121	152	145	8
	Countersloping $\frac{1}{8}$ ..				50	..	88	102	88	9
	Sloping at $\frac{1}{6}$				85	.	98	96	....	10
	Countersloping $\frac{1}{6}$ ..				51	..	114	120	160	11
	Do .... Do. ..				51	8	182	180	....	12
	Sloping at $\frac{1}{5}$	26	10	455	134		146	149	140	13
	Countersloping $\frac{1}{5}$ ..				90	12	266	293	263	14
	Sloping at	26	12	546	180	..	188	181	178	15
	Countersloping $\frac{1}{5}$ ..				131	12	257	373	402	16
With Foundations of rammed Earth, equal in Depth to $\frac{1}{11}$th of the total Height.	Countersloping $\frac{1}{8}$	26	4	182	$12\frac{1}{4}$	−24	76	69	69	17
						..	129	170	200	18
						8	196	151	178	19
	Countersloping $\frac{1}{5}$	26	4	182	$12\frac{1}{2}$	24	84	87	83	20
						..	279	....	....	21
						8	426	349	360	22
	Leaning at $\frac{1}{6}$	26	4	182	25	..	$65\frac{1}{2}$	$58\frac{1}{2}$	$54\frac{1}{2}$	23
						8	$100\frac{1}{2}$	$97\frac{1}{2}$	$107\frac{1}{2}$	24
	Countersloping $\frac{1}{8}$	26	6	273	$27\frac{1}{2}$	−24	90	94	94	25
						..	265	311	307	26
						8	321	290	321	27
	Countersloping $\frac{1}{5}$	26	6	273	29	24	101	97	97	28
						..	461	405	433	29
						8	517	489	446	30
	Leaning at $\frac{1}{6}$	26	6	273	59	..	121	$117\frac{1}{2}$	124	31
						8	251	259	256	32
	Rectangular	26	8	364	47	−24	78	88	90	33
						8	209	181	181	34
	Countersloping $\frac{1}{8}$	26	8	364	50	−24	154	146	150	35
						..	378	462	349	36
						8	294	349	384	37
	Countersloping $\frac{1}{5}$	26	8	364	51	−24	139	185	139	38
						..	538	671	461	39
						8	531	518	517	40
	Leaning at $\frac{1}{6}$	26	8	364	86	..	$130\frac{1}{4}$	$128\frac{1}{2}$	$132\frac{1}{2}$	41
						10	299	353	334	42
	Countersloping $\frac{1}{5}$	52	8	364	55	..	202	304	306	43
						12	434	462	415	44

TABLE XV.

Description of the Models used, &c.	Without Earth. Revetm.t Height.	Revetm.t Mean Thickness.	Counterforts Length	Counterforts Width, or Mean Width	Counterforts Central Interval	Total. Weight.	Total. Mean Stability, standing loose.	With rammed Earth. Height of Earth	Stability in Trials, 1st	2d	3d	No. of the Experiment.
With Foundations of rammed Earth equal in Depth to 1/12th of total Height.												
Countersloping 1/6 ……	52	10[illegible]	..	..	..	946½	95	..	420	419	416	45
								12	559	517	524	46
Sloping at 1/6 ………	52	13	.	..	..	1183	259	..	370	319	355	47
								12	630	637	61[illegible]	48
Countersloping 1/6 ……	52	13	.	..	..	1183	165	..	589	597	60[illegible]	49
								12	717	720	…	50
Countersloping 1/5, with three Offsets in Rear	52	13	..	..	..	11[illegible]3	157	..	708	708	722	51
								12	1043	1015	1012	52
Countersloping 1/5, with rectangular Counterforts …………	26	4	4	4½	18	227½	23	24	147	160	….	53
								..	322	475	422	54
								8	489	492	….	55
Countersloping 1/5, with diminished Counterforts …………	26	4	4	5	18	230½	23¼	24	133	128	136	56
								..	476	520	461	57
								8	619	161	575	58
Countersloping 1/5, with dovetailed Counterforts …………	26	4	4	5	18	230½	24	24	217	209	203	59
								..	685	685	….	60
								8	685	675	….	61
Sloping at 1/5, with rectangular Counterforts …………	26	6	6	4½	18	341¼	84	24	190	169	171	62
								..	528	475	557	63
								12	611	807	800	64
Sloping at 1/5, with diminished Counterforts …………	26	6	6	5¼	18	346	86	24	250	237	235	65
								..	315	358	407	66
								12	514	510	….	67
Sloping at 1/5, with dovetailed Counterforts …………	26	6	6	5¼	18	346	87	24	313	293	349	68
								..	672	629	….	69
								12	629	665	741	70
Countersloping 1/5, with rectangular Counterforts …………	26	6	6	4½	18	341¼	55	24	307	308	310	71
								..	657	629	633	72
								12	733	685	797	73
Countersloping 1/5, with diminished Counterforts …………	26	6	6	5¼	18	346	56	24	213	259	251	74
								..	587	566	585	75
								12	619	909	825	76
Countersloping 1/5, with dovetailed Counterforts …………	26	6	6	5¼	18	346	58	24	263	269	273	77
								..	640	629	714	78
								12	685	717	705	79
Leaning at 1/5, with rectangular Counterforts	26	6	6	4½	18	341¼	92	..	671	688	678	80
								12	1045	1045	1045	81
With no Foundation in Front.												
Sloping at 1/5, with diminished Counterforts	26	6	6	5¼	18	346	86	..	304	307	….	82

It will be observed, on inspecting the tables contained in this chapter, that some of our experiments, both with shingle and rammed earth, were tried with a set of larger models, 52 inches high. These high models, had respectively a thickness or mean thickness, either of 8 inches, 10⅔ inches, 12 inches, or 13 inches, and weighed from 728 to 1183 lbs.; and consequently being rather too unwieldy to have answered for a general course of experiments, they were provided merely for the purpose of ascertaining, whether the results, obtained by means of small models, as to the comparative stability of profiles of various descriptions, were likely to hold good, in judging of the strength of similar profiles on a much larger scale: and this important question appears to have been determined in the affirmative.

For example, by experiment 11 (*See Table* I.), it appears that the small countersloping model for supporting shingle, whose height is 26 inches, mean thickness 4 inches, and counterslope one fifth, has no stability, but oversets as soon as the shingle is raised to the level of the top of the supposed revetment. In like manner it appears by experiment 80 (*See Table* III.), that the high countersloping model, exactly similar to the former, but double in height and in mean thickness, has also no stability for supporting shingle, as it falls in consequence of the pressure, as soon as the shingle is raised to within one inch of the top of the supposed revetment.

As a second example, it appears by experiment 12 (*See Table* I.), that the rectangular model, whose height is 26 inches, and its mean thickness 6 inches, when backed with shingle so as to represent a counterscarp revetment, has a stability of 4½ lbs. only. And in like manner it appears, by experiment 81 (*See Table* III.), that the high rectangular model, which is exactly similar to the above model, but double its height and thickness, when backed with shingle so as to represent a counterscarp revetment, has a stability of 18 lbs.; and these two results are nearly in the same proportion to the original stability of their respective models, before any

shingle was applied to either of them. And on further comparing the several other experiments, made under various circumstances, with the high models, and those made, under the same circumstances, with the corresponding low ones of a similar description, as recorded in the tables, it will be found, that they in general decidedly tend to establish the same conclusion, although so very close a coincidence will not always be remarked, as in those particular instances, which I have just quoted.

In order, however, to ascertain still more fully this very important point, I had a much larger model made, than any that have yet been noticed, the height of which was 104 inches, and its mean thickness $29\frac{7}{15}$ inches, which is in the proportion of $\frac{17}{60}$ths of the height. This model weighed no less than 5363 lbs., and it required to be backed with quantities of shingle in proportion, much greater than any we had before used, so that the simple apparatus, that had sufficed in all our former experiments, was of course entirely inadequate. Accordingly, before any use could be made of this new model, we were under the necessity of fitting up a place on purpose with strong timbers and planking, and the process of each individual trial became exceedingly laborious.* On comparing the results of the experiments, tried with this very large model, and those that had been previously tried with the corresponding low model, whose height was 26 inches, and mean thickness $7\frac{11}{30}$ inches, we found, that they also agreed so far, as to warrant us in drawing from them the same general inference, that has already been stated; and from the very great scale of the experiments, now alluded to, they will no doubt be allowed to be peculiarly decisive.

Upon the whole, therefore, I conceive, that the course of experiments, tried with our small models of 26 inches in height, and of

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* This very large model, and the apparatus necessary for using it, were prepared, and all the experiments made with it were conducted, by Lieut. H. P. Bruyeres of the Royal Engineers.

various mean thicknesses and slopes, may be applied with confidence, to determine the proper proportions of any other solid bodies, of a much greater height, such as revetments of masonry, intended to resist the pressure of loose earth.*

It is to be remarked, that excepting in fortresses, founded on loose sand or shingle, which situations seldom occur, the ramparts and parapets are usually formed of soil of a certain tenacity, which is either actually rammed, or at least very nearly the same effect is produced, in the process of the work, by the constant passage of carts, and wheelbarrows, conveying materials. Hence, in most cases, the revetments of a fortress have very little pressure upon them, of such a nature as can tend to overset them, since they are almost always backed with tenacious earth, the cohesion of which, particularly if counterforts are used, must, on the contrary, add a vast stability to the masonry. But it is by no means prudent to calculate upon a continuance of this state of things, in regulating the profiles of a fortress; for the tenacity of the supported earth of a rampart, &c. however great it may originally have been, is always liable to be deranged by the effects of rain and frost; so that large masses of earth, which at first may not have acted upon the masonry, excepting in the favourable mode that was before alluded to, may suddenly be brought to press upon it with considerable force, and with a decided tendency to overthrow it. Some particular kinds of soil, also, such as clay for example, are known to swell or increase in magnitude, after imbibing a certain quantity of moisture; and when this happens, it is evident, that they must

* It is to be observed in favour of the safety of the conclusions, that are to be drawn from our experiments, that our models were all rather lighter than the shingle, and considerably lighter than the rammed earth, which was applied to them; whereas it is well known that the specific gravity of the masonry of revetments is generally greater than that of the supported earth.

exert a great lateral thrust, unfavourable to stability. Under these considerations, it may, consequently, be allowed to be advisable, at least in northern climates, to give to all revetments, even in the stiffest kinds of earth, the same degree of strength that would be necessary, if the soil to be supported consisted of very loose sand or shingle. The rules therefore, which are about to be laid down, in regard to the proper dimensions of revetments of different descriptions, have been deduced entirely from the experiments contained in those tables, that relate to shingle only.

RULE I. *In revetments of equal height, and mean thickness, the strength of each is in proportion to its slope; the rectangular profile, which has no slopes, being the weakest.*

REMARK.

This is proved by our first course of experiments with shingle, contained in the first seven tables of this chapter, in which the countersloping, sloping, or leaning profile of $\frac{1}{8}$th, has always an intermediate degree of stability, being weaker than the countersloping, sloping, or leaning profile of $\frac{1}{5}$th, but stronger than the rectangular profile of the same height and cubic contents.

RULE II. *Of all sloping revetments of equal height and mean thickness, that can be used, the countersloping profile is the most suitable for works of fortification.*

REMARK.

By the experiments with shingle in general, as recorded in the various tables, it appears that in profiles without counterforts, whose mean thickness is equal to $\frac{17}{60}$ths of the height or upwards, the countersloping profile exceeds all others of equal height and mean thickness in stability: but in less substantial profiles, that is to say, in such, whose mean thickness is not greater than $\frac{1}{4}$th of the height, the countersloping profile is weaker than either the corres-

ponding sloping, or leaning profile.* The difference, however, is not so considerable, as to counterbalance a peculiar and most important advantage of the former construction, which shall now be stated. This consists in the perpendicularity of the exterior surface of the countersloping profile, which renders it much more durable than any of the other sloping forms; for it is evident, that the counterslope of the first-named profile, upon which its strength depends, may be laid out in any proportion, judged necessary without prejudice to the masonry. In the leaning and common sloping pro-

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* Besides the peculiar profiles, that have been noticed in the text, a revetment may be built with double slopes, that is to say, with an exterior slope in front, and a counterslope in rear. If this construction were used, as for example, if a revetment of a given height and mean thickness had an exterior slope of one tenth, and a counterslope of one tenth, the increase of thickness at the base being consequently equal to one fifth of the height; its stability would probably, under any given circumstances, be very nearly in a mean proportion between that of the sloping and countersloping profiles of the same height and mean thickness, whose slopes were in the proportion of one fifth of the height. But if the slope and counterslope of a doubly-sloping revetment were unequal, as for example, if its slope were equal to one thirtieth, and its counterslope equal to one sixth of the height, its stability would still be in some intermediate proportion between that of the common revetment sloping at one fifth, and of the countersloping revetment, having a counterslope of one fifth, the said proportion ($\frac{1}{5}$th) being equal to the sum of the slope and counterslope ($\frac{1}{30}$th + $\frac{1}{6}$th) of the doubly sloping revetment added together.

From these considerations, it may be allowed, that there can be no doubt of the compound profile, which has just been described, possessing considerable stability. If therefore any Engineer, in planning a fortress, should wish to adopt the countersloping profile for his revetments, and yet should not choose to have them quite perpendicular in front; he may give them an exterior slope of $\frac{1}{60}$th, and a counterslope of $\frac{11}{60}$ths of the height, which in a scarp revetment of thirty feet will allow 6 inches for the base of the former, and 5 feet 6 inches for that of the latter; so that the total gain of thickness of masonry at bottom will be equal to $\frac{1}{5}$th of the height. I conceive, that there would be little or no difference, in point of strength, between a profile of the above construction, and a perfect countersloping revetment of the same height and mean thickness.

files, on the contrary, if their slopes are small, their strength will not greatly exceed that of the rectangular, which has been proved to be the weakest of all profiles. If on the other hand, with a view to avoid this evil, that necessary degree of slope, which is essential to strength, should be given to them; then they will be exposed to the destructive effects of rain, frost, and vegetation, which by lodging in, and acting upon, the joints of the masonry, will in process of time entirely destroy the cohesion of the mortar, and ruin the exterior surface of the wall.

Having thus stated a property of the countersloping profile, which, I conceive, renders it, upon the whole, by far the most suitable for the scarp and counterscarp revetments of fortresses, or of other works, in which the external surface of the masonry is exposed to the action of air and weather, only; I shall remark, that in all retaining walls, such as those of wharfs, wet docks, &c., in which the greater part of the masonry is generally under water, there will be little or no difference, in point of durability, whether the exterior surface is vertical or sloping, as the action of the water will be equal in both cases. Consequently in works of this last-mentioned description, particularly if building materials are very expensive, the countersloping profile may be rejected, and the leaning profile chosen in preference; because our experiments with shingle prove, that, in revetments backed with loose soil, the mean thickness of masonry of the countersloping profile cannot with propriety be reduced so low, as may be done with safety, either in the leaning or common sloping revetment.

RULE III. *No revetment should ever be built without counterforts; and yet, in determining the dimensions of any profile, the thickness or mean thickness of the revetment should be such, that, even if deprived of its counterforts, it would have some stability.*

REMARK.

To enlarge upon the great utility of counterforts, after what was before said, will be superfluous, particularly as a reference to the various experiments will show their utility in the strongest light. For example, by experiment 44 (*See Table* II.), it appears that the rectangular model, 26 inches high and 8 inches thick, when used as a partial revetment without a berm, had so very little stability that it fell of itself after the shingle was raised about 24 inches above the top of it; whereas by experiment 127 (*See Table* V.), it also appears, that the rectangular model of the same height, whose thickness was only 6 inches, was so much strengthened by the addition of counterforts, equal in cubic contents to one fourth of the supposed revetment, that when loaded with shingle under the same circumstances to the height of 60 inches above the top of it, it acquired a stability of 70 lbs., which was considerably greater than its original stability, before any shingle was applied. Now the cubic contents and weight of the 8-inch model, are greater than those of the 6-inch model and of its counterforts added together; and yet, as it has just been shown, the former is much the weakest; from whence it follows, that of two profiles of revetments, both of the same height, and containing the same quantity of masonry, and consequently built at equal expense, but of which the one has counterforts, and the other none, the masonry of the first may be exceedingly strong, whilst that of the second, having little stability, will fall down, as soon as it is backed with loose earth to a certain height.

Notwithstanding, however, the great additional strength, which is undoubtedly to be derived from the use of counterforts, it would, by no means, be prudent, in trusting to them, to diminish the quantity of masonry, in any revetment, beyond a certain limit. For it is to be observed, that masonry seldom becomes united into one homogeneous mass, like rock, until after the lapse of a great number of years; and not even then, unless the mortar is of a

peculiarly good quality, which, in all countries and under all circumstances, is not to be expected. Consequently, in building walls with counterforts, for any given profile, that kind of revetment should certainly not be adopted, which if deprived of its counterforts, would have little or no stability; because although the profile might be sufficiently strong, provided that the whole mass adhered together, it is possible, that the pressure of loose earth might, under the circumstances supposed, overcome the cohesion of the masonry, and force it asunder in various places, in such a manner, as to throw down the greatest part of the revetment, leaving the counterforts, and the lower parts of the wall, standing.*

RULE IV. *Counterforts should be rectangular: their length should not be greater than the mean thickness of masonry of the revetment; and their clear intervals should not exceed from two to three times the said mean thickness. Their width should not be greater than one fourth of their central intervals.*

REMARK.

With respect to the best form for counterforts, the general result of our experiments with rammed earth, seemed to prove, that in soil of a very tenacious quality, the diminished counterfort is rather weaker than the rectangular, and that the latter is a little weaker than the dove-tailed kind: but as the difference is very trifling, and as,

* Under what circumstances, a wall of given dimensions may be torn from its counterforts and foundation, by a pressure of earth, must remain doubtful, until experiments are tried with actual revetments, on a sufficiently large scale. But it is to be remarked, that the mean thickness and other dimensions, which ought to be given to any revetment, in order to enable it to resist a certain pressure of loose earth, without the assistance of counterforts, may be determined with sufficient accuracy, by means of our experiments with shingle.

from some experiments with shingle, before alluded to, but not entered in any of the tables, we found, that in loose soil, there was little or no difference of stability between the various forms that have been enumerated, I am of opinion, that the rectangular counterfort, as being the simplest and easiest of construction, ought to have the preference.

It was explained in the foregoing chapter (*See pages* 513, 514, *and* 515), that not only the dimensions of counterforts, but also their intervals, may admit of great variety, without making any difference whatever, in the quantity of masonry used in the construction of them. But the effect of counterforts, in strengthening a revetment, may, with propriety, be compared to that of the beams, which support the superstructure of a wooden bridge. Although these beams should, in themselves, be more than sufficient to sustain a much greater weight, than any that is likely to pass over the bridge, if it could be applied to them individually; yet if they are placed at too great intervals apart, this excess of strength will be of no avail, for the planks above them may give way, and the bridge will be rendered impassable. In like manner, if counterforts are built too distant from each other, the intermediate portions of the revetment may not derive the necessary aid from them. Some limit should therefore be assigned to the clear intervals of any system of counterforts, which ought not to be exceeded in practice; and probably that, which has been laid down, in the rule just stated, may appear a proper maximum.

When the advantages of two kinds of counterforts, both equal in quantity of masonry, and placed at equal central intervals apart, but of different lengths, are taken into consideration, it will appear, that long and narrow ones will be much more favourable to stability, than shorter and wider ones; whilst, on the other hand, the latter will unite better with the body of a revetment, and will be less likely to be separated from it, by any extraordinary pressure of

loose earth, than the former. The length, therefore, of counterforts ought to have its limits; and our experiments have proved, that even when the proportional mean thickness of our models, as compared with their height, was less than would be advisable for actual revetments, the dimensions laid down in our present rule for the proportional length and width of counterforts yielded more than sufficient strength. I have therefore given these dimensions as a maximum, that ought not to be exceeded; but they may be reduced in a certain degree, without inconvenience.*

RULE V. *The dimensions proper for Full Scarp revetments, without berms, and for Demirevetments, or for Partial Scarp revetments, having berms equal in width to one fourth of the height of masonry or upwards, are as follows.*

Make your profile countersloping, with a counterslope of one fifth, and a mean thickness equal to seventeen sixtieths of the height, and give it counterforts, equal in length to one fifth of the height, placing them at central intervals of four times their width apart.

REMARK.

Experiments 402, 403, 404, and 405, in Table XIII, prove, that a revetment countersloping at one fifth, having a mean thickness of one fourth of the height only, which is considerably less than I have recommended in the above rule, but having counterforts of the proportions therein prescribed, is sufficiently strong either for a demirevetment, or partial scarp revetment, for supporting loose earth to any required height; and experiments 280, 281, and 282, in Table X, prove, that a profile of the proportions laid down in this rule

* The counterforts, used by the civil engineers in this country, for wharf walls, &c., have generally been built square, and at central intervals of eighteen feet apart; their length varying from about one half to two thirds of the thickness, or mean thickness, of the revetment.

would have considerable strength as a demirevetment or partial scarp revetment, with a berm, even if it were entirely deprived of its counterforts. The same inferences are to be drawn from the experiments tried with the higher models, as will be seen by referring to the tables, so that upon the whole, I conceive, that there can be no doubt of the stability of the profile now suggested. On comparing the above, when used as a full scarp revetment, with Vauban's general profile, it will be found that in revetments 30 feet high, there is a very small saving of masonry by adopting the former profile; but in revetments lower than the above height, the saving is more considerable: whilst, on the contrary, Vauban's profile is the most economical, if the height of the revetment exceeds 35 feet; but this is seldom or never necessary in military works; so that, generally speaking, the profile, above recommended by me, must be allowed to be the least expensive of the two.*

RULE VI. *The dimensions proper for Demirevetments and for Partial Scarp revetments, without berms, are as follows.*

Make your profile countersloping, with a counterslope of one fifth, and a mean thickness equal to three tenths of its height, and give it counterforts, equal in length to one fifth of the height, placing them at central intervals of four times their width apart.

REMARK.

Of the strength of a revetment and counterforts of the proportions now recommended, there can be no doubt, since various experiments, contained in the tables, prove, that by aid of such counterforts, or even smaller ones, much weaker countersloping revetments, than the above, are capable of supporting loose earth

* In order to judge between the two profiles, compare Table II, Chapter XXIV, page 502, in which Vauban's general profile for full scarp revetments is analyzed, with Table A, afterwards given in page 628.

raised to any given height above them, whether with or without a berm. But as the tenour of our experiments proves, that if deprived of counterforts, the countersloping profile, when used as a partial scarp revetment, is generally weaker without a berm, than with one, excepting when the mean thickness is greater than seventeen sixtieths of its height; I have for this reason judged it prudent, to make the revetment somewhat more substantial, in the present rule, than in my former one, although to some readers the precaution may probably appear superfluous.

In order to compare this profile with Vauban's, we shall first suppose that a partial scarp revetment is to be built, 30 feet high, and that there is to be a height of 15 feet of earthen scarp over it, exclusive of the parapet. By Vauban's rule, as stated in page 523, the thickness at top of such a revetment ought to be 8 feet 4 inches, and its thickness at bottom ought to be 14 feet 4 inches, the mean being 11 feet 4 inches: to which ought to be added counterforts 11 feet long, having a mean thickness of 5 feet 5 inches, and placed at intervals of 15 feet apart. Consequently it will be found by calculation, that a revetment and counterforts, so proportioned, will be equal in quantity of masonry to a wall 30 feet high, having a mean thickness of 15 feet 3⅝ inches: whilst the partial scarp revetment and counterforts, recommended by me, will be equal in quantity of masonry to a wall of the same height, but having a mean thickness of 10 feet 6 inches only. Thus by adopting a partial scarp revetment of the dimensions prescribed in my present rule, in preference to Vauban's, there will be a saving of nearly one third in the quantity of masonry.

Again, if we suppose that a scarp of 40 feet in total height, exclusive of the parapet, is to be retained by a demirevetment of 20 feet; Vauban's rule, counterforts included, will require a quantity of masonry, such as would build a wall 20 feet high and 14 feet 8 inches thick: whilst the rule, above laid down by me, requires a quantity of masonry equal to a wall of the same height

that has been specified, but only 7 feet thick; so that by adopting the latter profile, in preference to Vauban's, under the circumstances now supposed, there will be a saving of masonry of more than one half.*

RULE VII. *The dimensions proper for Counterscarp revetments, Gorge revetments, or others, intended to retain simple terrepleins only, without parapets, are as follows.*

Make your profile countersloping, with a counterslope of one fifth, and a mean thickness equal to one fourth of the height, and give it counterforts equal to one sixth of the height, placing them at central intervals of four times their width apart.

REMARK.

The propriety of this rule is sufficiently proved by experiment 280, in Table IX, and experiment 401, in Table XIII, the former of which shows, that a counterscarp revetment of the dimensions herein prescribed would have considerable stability, even if deprived of its counterforts; whilst the latter proves, that by the addition of these, it becomes an exceedingly strong profile. The same inference, as to the sufficiency of the profile now recommended, is to be drawn from various other experiments, which I forbear to mention, as they will be seen by referring to the tables.

RULE VIII. *Although the dimensions of Scarp and Counterscarp revetments, found by the three preceding rules, are strong enough*

* The reader will clearly understand, that in drawing these comparisons, I do not pretend to say, that the countersloping profile, recommended by me for scarp revetments and demirevetments, is actually stronger than a common sloping profile of the same dimensions would be. As far as regards stability, the error lies, therefore, not in the slope or form of Vauban's profile, but in the great waste and superfluity of strength, given by him to his partial revetments, owing to his having reasoned upon false notions as to the nature of the pressure of loose earth.

for resisting any common pressure of earth, that is likely to act upon them, yet it will be advisable, in low profiles, to make some addition to the thickness of masonry, for the sake of durability: And the same precaution will also be proper, in profiles of every description, when the foundations are bad, or when the soil to be retained is of an uncertain quality, likely to vary, from time to time, between a state of dryness and humidity.

REMARK.

It will be obvious, that the durability of masonry, particularly in northern climates, must in a great measure depend upon its actual mass. For example, a revetment, 5 feet thick, will certainly be much more durable, than another which is only 2 feet thick, although considering them merely as retaining walls, their comparative strength, as opposed to a certain pressure of earth, acting upon them, may, in each, have originally been equal. Under this consideration, the first part of the rule, which has just been laid down, appeared expedient.

RULE IX. *In revetments, intended to retain soil of any tenacity, those parts of the masonry, which are to come in contact with the supported earth, should be built rough or irregularly, with the stones or bricks occasionally projecting a little.*

REMARK.

As the propriety of this rule is sufficiently proved by the experiments with rammed earth, which show the advantages, arising from the kind of friction or cohesion, that the mode of construction, now recommended, must evidently tend to increase; I shall only observe, that, in countersloping profiles, the offsets in rear, which are always advisable, will produce the desired effect, as far as regards the back of the revetment, and the tail of each counterfort, without the necessity of attempting any other irregularity in this portion of the work.

RULE X. *It is, in all cases, advantageous, but, in unfavourable soil, absolutely necessary, to lay out the foundations of revetments according to an inclined plane, a little deeper in rear than in front.*

REMARK.

As this rule applies most particularly to unfavourable foundations, which are specially treated of in the following chapter, the reason of it will there be explained. When the base of the masonry is considerable, it will generally be more convenient, and at the same time equally serviceable, to lay out the front part of the foundation, only, according to an inclined plane of the above description, making the remainder of it, towards the rear, horizontal, or nearly so.

RULE XI. *The exterior joints of the masonry of military revetments should always be horizontal.*

REMARK.

The mode of construction, now suggested, is scarcely ever practised with walls having an exterior slope, because it would lead to a waste of materials, in building with stone, and would be very inconvenient, in using bricks. The joints of common sloping, or of leaning revetments have, therefore, been almost always laid out according to an inclined plane, perpendicular to the exterior slope; and thus the rain water falling on the external surface, is enabled to lodge itself, and penetrate into the body of the masonry, with greater ease, than if the joints were horizontal. As compared with the above profiles, the countersloping revetment has therefore a great advantage; namely, that the best and most proper mode, of laying the exterior courses of the masonry, is also the most convenient in practice.*

* It has been remarked, in various parts of the continent, that perpendicular towers, and walls of considerable antiquity, constructed either by the

RULE XII. *When a revetment is backed with solid rock for about one fourth or one third of its height, and from thence upwards with loose earth, the lower part of the masonry must be united to the rock, by short counterforts and projections; which being done, its thickness may be diminished to much less than the usual dimensions allotted to profiles of that height: but as far as regards the remainder of the revetment, it must have the same mean thickness, and counterforts of the same proportions, as if there were no rock behind any part of it, care being taken, not by any means to make the upper part of the masonry weaker, but on the contrary, rather stronger, on account of the rock.*

REMARK.

The case now supposed is one, which is often likely to occur in practice; and at the same time it is one, in which, of all others, failure is most likely to ensue, if erroneous principles are acted upon. I therefore judged it best to be explicit as to this particular case, although the propriety of adopting the precautions recommended might perhaps have been sufficiently inferred, from a care-

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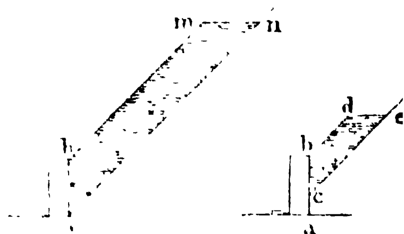
ancient Romans, or in the feudal ages, are in a good state of preservation, whilst the exterior surface of the masonry, in the revetments of modern fortresses, built by Vauban and others, on the same spot, and apparently with materials of the same quality, has gone entirely to decay. In the Citadel of Antwerp, I observed that scarcely any of the cut stone, with which the revetments had originally been coated, remained in a serviceable state. A few years ago, it was found necessary to new face a considerable part of the revetments of Portsmouth. Such are the disadvantages attending exterior slopes, especially when the joints of the masonry are not horizontal.

In the retaining walls of wharfs, harbours, or wet docks, which are often under water for a considerable part of their height, it will be evident, for a reason before stated, that the form of the exterior surface, and the direction of the joints, are of less importance, particularly as water-proof cement either is or ought to be used in such works, which, as being too expensive, it is not common to employ in military revetments, or other buildings, exposed to the effects of weather only.

ful perusal of the foregoing parts of this chapter, without my having introduced a special rule on the subject. For it must be evident, that if the lower part of a revetment is backed with rock, but no means are taken to unite them together, there will be no pressure whatever upon the base of the wall; so that the pressure of loose earth, which acts upon the upper part of the masonry, with a tendency to overset the revetment, not being at all counteracted, as in a common profile, by any pressure or force favourable to stability, will have a much greater power of effecting the fall of the revetment, than if the masonry were entirely backed with loose earth from the bottom upwards. Hence a revetment partially backed with rock, will be much weaker on that account than a common revetment, if the precautions recommended in the above rule are neglected. But if these are adopted, in the execution of the work, the lower part of the masonry will be so firmly united to the rock, that it will be impossible for the pressure of loose earth acting upon the upper part of it to overset the revetment, without breaking the wall to pieces, which will also be impossible, if those parts of the revetment and counterforts, which are above the level of the rock, have the dimensions recommended in the rule now under discussion.

By way of further illustration, I shall state some experiments which fully prove the truth of what has just been advanced.

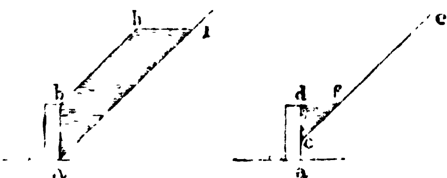
1st. We took the 8-inch rectangular model, 26 inches high, and backed it with a mass of shingle, a b m n, pressing upon the whole of the back of it, from the bottom upwards, and raised to the height of 60 inches over the top of it, as shown in the first of the annexed figures, so as to represent a partial scarp revetment, having a berm equal to the thickness of masonry. On trying the average stability



of our profile, under the above circumstances, it proved to be equal to 12½ lbs.

2dly. By means of an oblique board, e c, united at bottom to the top, c, of a small vertical board 8 inches high, supposed to be placed close to the back of the same model, in the position, a c, as shown in the second of the above figures, we were enabled to apply a mass of shingle, c b d e, so as to press on the upper part, c b, only of the back of the supposed revetment, there being no pressure whatever on the lower part, a c, of the back of it. It will be evident, that, under the circumstances stated, the model is, in this figure, exactly in the same predicament, as a revetment backed with rock for about one third of its height, measuring from the base, and from thence upwards with loose earth; and the result of our experiments proved that it was much weaker in this case, than in the former, for it had no stability whatever, but fell of itself by the pressure of the smaller mass of shingle, c b d e, without using the scale or weights, as soon as that loose material was raised to a level, d e, only 17 inches higher than the top, b, of the model. Thus, in this case, the quantity of shingle represented by the trapezoid, c b d e, which overset the model, was only equal to about one fourth of the quantity of shingle, represented by the greater trapezoid, a b m n, in the first figure, which proved incapable of oversetting it.

3dly. In like manner, on trying the 6-inch rectangular model, also 26 inches high, in the manner represented in the first of the two following figures, it fell of itself by the mass of shingle, a b h i, as soon as that loose material was raised to a level, h i, 36 inches higher than the top, b, of the supposed revetment, the supported mass being in this case allowed to act upon the whole of the back of the model.



4thly. But on applying shingle to the same 6-inch model, in the manner represented in the second figure, so as to press upon the

upper part, c d, of the back of the model only, there being no pressure whatever upon the lower part of it, a c, for the height of 8 inches from the base upwards; the supposed revetment fell of itself under the pressure of the much smaller triangular mass of shingle, c d f, as soon as that material was raised to the level of the top of the model. Thus the quantity of shingle, which proved capable of oversetting the model, under the circumstances of our present case, was only equal to about one eighth part, of what had been found necessary for oversetting it, under the circumstances of our former case. Like results were invariably obtained by experiments tried with several of our other models, under similar circumstances, which it would be superfluous to mention.*

For the conveniency of the reader, I shall now insert three new tables of revetments, marked, A, B, and C, which have been calculated according to the fifth, sixth, and seventh of the foregoing rules. The first applies to full scarp revetments, without berms, and to partial scarp revetments or demirevetments, having berms equal in width to one fourth of the height of masonry or upwards: the second applies to demirevetments or to partial scarp revetments without berms: the third applies to counterscarp or gorge revetments.

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* In the execution of the new Dock works at Plymouth, which were commenced about seven years ago, the scarp revetment was, in several places, backed with slate rock, for a considerable portion of its height upwards, the upper part of the masonry only being exposed to a pressure of loose rubbish. Contrary to the general expectation, it was observed that the particular parts of the revetment, now alluded to, seemed less capable of resisting this partial pressure, than the other parts of the same revetment, that were exposed to a general pressure of loose rubbish. Consequently, it was soon found necessary to abandon the idea, which had at first been suggested, of dispensing with counterforts, in those peculiar portions of the revetment, that were backed with rock towards the bottom. I avail myself of this piece of information, which was communicated to me by an Engineer Officer, employed at Plymouth at the time the remark was made, as a practical confirmation of the truth of the principles of revetments, deduced by me from my experiments with shingle. I was not aware, that such a circumstance had occurred, until the first sheets of this chapter were actually sent to press.

Table A.

Dimensions proper for Full Scarp Revetments without Berms, and for Demirevetments, and Partial Scarp Revetments, having Berms, equal in width, to one fourth of the Height of Masonry.

Height of the Walls.	Revetment.		Counterforts.			Mean Thickness of the Revetment.	Mean Thickness of a Wall equal to the Revetment and Counterforts	Quantity of Masonry in One Running Yard of Profile.	Nature of the Profile.
	Thickness at Top.	Thickness at Bottom.	Length.	Mean Width	Central Distance.				
Feet.	Ft In	Ft In.	Ft In.	Ft. In.	Ft In	Ft In.	Ft. In	Cubic Yards.	
10	1 10	3 10	2 0	2 6	10 0	2 10	3 4	3·7	The Revetment and Counterforts are supposed to be countersloping at 1/5th, with Offsets in Rear.
12	2 2 2/5	4 7 1/5	2 4 4/5	2 9	11 0	3 4 1/5	4 0	5·333	
14	2 6 4/5	5 4 2/5	2 9 3/5	3 0	12 0	3 11 3/5	4 8	6·37037	
15	2 9	5 9	3 0	3 1 1/2	12 6	4 3	5 0	8·3333	
16	2 11 1/5	6 1 3/5	3 2 2/5	3 3	13 0	4 6 2/5	5 4	9·2592	
18	3 3 3/5	6 10 4/5	3 7 1/5	3 6	14 0	5 1 1/5	6 0	12·0	
20	3 8	7 8	4 0	3 9	15 0	5 8	6 8	14·8148	
22	4 0 2/5	8 5 1/5	4 4 4/5	4 0	16 0	6 2 4/5	7 4	17·9259	
24	4 4 4/5	9 2 2/5	4 9 3/5	4 3	17 0	6 9 3/5	8 0	21·3333	
25	4 7	9 7	5 0	4 4 1/2	17 6	7 1	8 4	23·1481	
26	4 9 1/5	9 11 3/5	5 2 2/5	4 6	18 0	7 4 2/5	8 8	25·0370	
28	5 1 3/5	10 8 4/5	5 7 1/5	4 9	19 0	7 11 1/5	9 4	29·0481	
30	6 5	11 6	6 0	5 0	20 0	8 6	10 0	33·3333	
32	5 10 2/5	12 3 1/5	6 4 4/5	5 3	21 0	9 0 4/5	10 8	37·9259	
34	6 2 4/5	13 0 1/5	6 9 3/5	5 6	22 0	9 7 3/5	11 4	42·8148	
35	5 6	13 5	7 0	5 7 1/2	22 6	9 11	11 8	45·1851	
36	6 7 1/5	13 9 1/5	7 2 2/5	5 9	23 0	10 2 2/5	12 0	48·0	
38	6 11 3/5	14 6 4/5	7 7 1/5	6 0	24 0	10 9 1/5	12 8	53·4814	
40	7 4	15 4	8 0	6 3	25 0	11 4	13 4	59·2592	

Table B.

Dimensions proper for Demirevetments and Partial Scarp Revetments without Berms.

Height of the Walls.	Revetment. Thickness at Top.	Revetment. Thickness at Bottom	Counterforts. Length	Counterforts. Mean Width.	Counterforts. Central Distance.	Mean Thickness of the Revetment	Mean Thickness of a Wall equal to the Revetment and Counterforts.	Quantity of Masonry in One running Yard of Profile.	Nature of the Profile.
Feet.	Ft. In.	Ft. In	Ft In	Ft. In.	Ft In.	Ft In.	Ft. In.	Cubic Yards	
10	2 0	4 0	2 0	2 6	10 0	3 0	3 6	3·8888	The Revetment and Counterforts are supposed to be countersloping at 1/5th, with Offsets in Rear.
12	2 4⅘	4 9⅗	2 4⅘	2 9	11 0	3 7⅕	4 2⅖	5·6	
14	2 9⅗	5 7⅕	2 9⅗	3 0	12 0	4 2⅖	4 10⅘	7·6222	
15	3 0	6 0	3 0	3 1½	12 6	4 6	5 3	8·75	
16	3 2⅖	6 4⅘	3 2⅖	3 3	13 0	4 9⅗	5 7⅕	9·9555	
18	3 7⅕	7 2⅖	3 7⅕	3 6	14 0	5 4⅘	6 3⅗	12·6	
20	4 0	8 0	4 0	3 9	15 0	6 0	7 0	15·5555	
22	4 4⅘	8 9⅗	4 4⅘	4 0	16 0	6 7⅕	7 8⅖	18·8222	
24	4 9⅗	9 7⅕	4 9⅗	4 3	17 0	7 2⅖	8 4⅘	22·4	
25	5 0	10 0	5 0	4 4½	17 6	7 6	8 9	24·3055	
26	5 2⅖	10 4⅘	5 2⅖	4 6	18 0	7 9⅗	9 1⅘	26·0288	
28	5 7⅕	11 2⅖	5 7⅕	4 9	19 0	8 4⅘	9 9⅗	30·4888	
30	6 0	12 1	6 0	5 0	20 0	9 0	10 6	35·0	
32	6 4⅘	12 9⅗	6 4⅘	5 3	21 0	9 7⅕	11 2⅖	39·8222	
34	6 9⅗	13 7⅕	6 9⅗	5 6	22 0	10 2⅖	11 10⅘	44·9555	
35	7 0	14 0	7 0	5 7½	22 6	10 6	12 3	47·6388	
36	7 2⅖	14 4⅘	7 2⅖	5 9	23 0	10 9⅗	12 7⅕	50·4	
38	7 7⅕	15 2⅖	7 7⅕	6 0	24 0	11 4⅘	13 3⅗	56·1555	
40	8 0	16 0	8 0	6 3	25 0	12 0	14 0	62·2222	

TABLE C.

Dimensions proper for Counterscarp Revetments, Gorge Revetments, or others intended to retain simple Terrepleins without Parapets.

Height of the Walls.	Revetment.		Counterforts.			Mean Thickness of the Revetment	Mean Thickness of a Wall equal to the Revetment and Counterforts	Quantity of Masonry in One running Yard of Profile.	Nature of the Profile.
	Thickness at Top.	Thickness at Bottom.	Length.	Mean Width.	Central Distance.				
Feet.	Ft. In.	Ft In.	Ft In	Ft In	Ft In	Ft In	Ft In	Cubic Yards.	
10	1 6	3 6	1 8	2 6	10 0	2 6	2 11	3·2407	The Revetment and Counterforts are supposed to be countersloping at ⅕th, with Offsets in Rear.
12	1 9⅗	4 2⅖	2 0	2 9	11 0	3 0	3 6	4·6666	
14	2 1⅕	4 10⅘	2 4	3 0	12 0	3 6	4 1	6·3518	
15	2 3	5 3	2 6	3 1½	12 6	3 9	4 4½	7·2916	
16	2 4⅘	5 7⅕	2 8	3 3	13 0	4 0	4 8	8·2961	
18	2 8⅖	6 3⅗	3 0	3 6	14 0	4 6	5 3	10·5	
20	3 0	7 0	3 4	3 9	15 0	5 0	5 10	12·9629	
22	3 3⅗	7 8⅖	3 8	4 0	16 0	5 6	6 5	15·6850	
24	3 7⅕	8 4⅘	4 0	4 3	17 0	6 0	7 0	18·6666	
25	3 9	8 9	4 2	4 4½	17 6	6 3	7 3½	20·2533	
26	3 10⅘	9 1⅕	4 4	4 6	18 0	6 6	7 7	21·9074	
28	4 2⅖	9 9⅗	4 8	4 9	19 0	7 0	8 2	25·4074	
30	4 6	10 6	5 0	5 0	20 0	7 6	8 9	29·1666	
32	4 9⅗	11 2⅖	5 4	5 3	21 0	8 0	9 4	33·1851	
34	5 1⅕	11 10⅘	5 8	5 6	22 0	8 6	9 11	34·0	
35	5 3	12 3	5 10	5 7½	22 6	8 9	10 2½	40·8333	
36	5 4⅘	12 7⅕	6 0	5 9	23 0	9 0	10 6	42·0	
38	5 8⅖	13 3⅗	6 4	6 0	24 0	9 6	11 1	46·7962	
40	6 0	14 0	6 8	6 3	25 0	10 0	11 8	51·8518	

In using the above tables, the precautions, given in the eighth and ninth rules, should be kept in mind, and attended to, where-ever it appears necessary; and in building with brick-work, if the dimension, laid down, involves any aukward fraction of a brick,* it ought to be rejected, and some other dimension, as nearly equal to it as possible, but free from that inconvenience, may be adopted

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* The size of bricks varies in different countries. The bricks commonly used in England, are about 9 inches long, $4\frac{1}{4}$ inches wide, and $2\frac{1}{2}$ inches thick. Consequently, a $1\frac{1}{2}$-brick wall implies one that is about 14 inches thick, a 2-brick wall implies one that is about 18 inches thick, a $2\frac{1}{2}$-brick wall implies one that is about 23 inches thick, &c. &c.

When the mortar is not applied too thick, 29 courses of bricks occupy about 7 feet in the height of a wall; and consequently about 425 bricks are required to build one cubic yard of brick-work, by which proportion the quantity of bricks necessary for completing the scarp revetments of a fortress may easily be calculated.

For example, if we suppose a fortress to be a regular decagon, having exterior sides of 384 yards, faces of 110 yards, and perpendiculars of 64 yards: the length of one front will be equal to 482·6 yards, as appears by referring to the first table, given in Chapter XVI *(See page 324)*, and therefore, as there are ten fronts, the total length of the scarp revetments of the main inclosure will be equal to $482{\cdot}6 \times 10 = 4826$ running yards. But if we further suppose these revetments to be 30 feet high, and constructed according to the fifth rule given in our present chapter, each running yard of profile will contain $33\frac{1}{3}$ cubic yards of brick-work, as may be seen without the trouble of calculation, by referring to Table A. The numbers 4826, and $33\frac{1}{3}$, must therefore be multiplied together, and the product, $160{,}866\frac{2}{3}$, will give the total number of cubic yards of brick-work required for the whole of the main inclosure of the supposed fortress. The result, thus obtained, must lastly be multiplied by 425, the number of bricks necessary for building one cubic yard, and the product 68,368,333 will show very nearly the number of bricks, which ought to be provided for building the scarp revetment and counterforts of the body of the place of the supposed decagon, according to the new profile suggested in this chapter. The above serves as a second specimen of the great facility, wherewith a rough estimate of the quantity of masonry, required for reveting a fortress of a given extent, may be drawn up, by means of the various tables contained in this book.

instead; as is always done, in civil works, in determining the dimensions of walls of inconsiderable thickness, such as those of dwelling houses, garden walls, &c., in which a half brick is the smallest fraction allowed.

CHAP. XXVI.

THE SAME SUBJECT CONTINUED.—IN WHAT MANNER THE PRESSURE OF EARTH UPON REVETMENTS MAY BE DIMINISHED, BY BREAKING ITS CONTINUITY—OF COUNTERARCHED REVETMENTS, CONCAVE REVETMENTS, AND CURVED LEANING REVETMENTS.—THAT THE SMALL INTERIOR REVETMENTS OF PARAPETS MAY SOMETIMES BE DISPENSED WITH.

From the experiments, recorded in the preceding chapter, it must appear sufficiently evident, that the nature of the action of the pressure of loose earth upon revetments has hitherto been generally misunderstood, and almost always greatly overrated.*

* It is proper to observe, that having been little employed in the construction of permanent works, I never had occasion to turn my mind much to the subject of revetments; and my object, in undertaking the present volume, was, rather to lay down, in a clear manner, such of the Elementary Principles of Fortification, as were generally received, than to attempt any new discoveries of my own. Chapter XXIV was accordingly written by me, as a statement of the doctrines, regarding the pressure of earth, &c., generally held by former writers upon this subject. It was begun without any suspicion of the fallacy of these doctrines; but when finished, I found the result, particularly as far as regarded partial revetments, of so very unsatisfactory a nature, that it gave rise to doubts in my mind; and I was induced to suspend the further prosecution of my book altogether, until I had tried the experiments, described in Chap. XXV, which have enabled me to lay down a very different theory of revetments, founded upon new principles.

Just as I had completed this last-mentioned chapter, I received from Paris a book that I had sent for upon the same subject (entitled, "Traité

Accordingly, various precautions have been recommended, and often adopted, in practice, with a view to diminish the said pressure, when, by reason of the great strength of masonry, no un-

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experimental, analytique, et pratique, de la Poussée des Terres, et des Murs de Revêtement,") written by Mr. Maynrel, a colonel of engineers in the French service, in which are detailed various theories of revetments, formed at different times, chiefly by Frenchmen, only one or two writers of other nations being noticed. Many of the theories or systems introduced, were papers presented to the Committee of Fortifications, by French engineer officers, from time to time, which, it would appear, there lay neglected and forgotten, until published in the work now alluded to. Of this class is a theory, found in the Depot of Fortifications, dated 1774, and written by an officer of Engineers, called Mr. Tersac de Montlong. This gentleman makes the same objection to the common doctrines of the pressure of earth, that afterwards occurred to me, namely, that there must be a certain portion of the supported mass, which tends to add stability to a revetment; and it is remarkable, that one theory, laid down by him, and reduced to an algebraical formula, is very nearly the same, which at first struck me as likely to prove correct, but which I ultimately rejected, on further consideration of the subject. (*See the note to page* 545.)

Mr. Tersac, in illustrating his doctrines, divides the supported mass into two portions, an upper and a lower, exactly in the same manner afterwards done by me; but whilst I agree with him, that the tendency of the lower portion is solely to stabilitate, — that part of his theory, which is founded on a supposition, that the upper portion tends with its whole weight and power solely to overset, must be set aside as erroneous, for I have proved, both by reasoning and by experiment, that the particles of loose earth composing it have a double action, tending not only to overset or weaken, but also to strengthen the revetment, and that, although the former force always appears to preponderate, it is often in a very small degree, so that in many cases, even although the actual weight of the upper portion of the supported mass of loose earth may be very great, as, for example, more than double that of the revetment upon which it presses; yet the diminution of stability, thereby occasioned to the profile, instead of bearing any proportion to so great a mass, may, comparatively speaking, be altogether inconsiderable and insignificant, not exceeding, for instance, one forty-fifth part of the original stability of the same profile, before any loose earth was applied to it. (*See from page* 545 *to page* 551; *and afterwards, from page* 591 *to page* 595.)

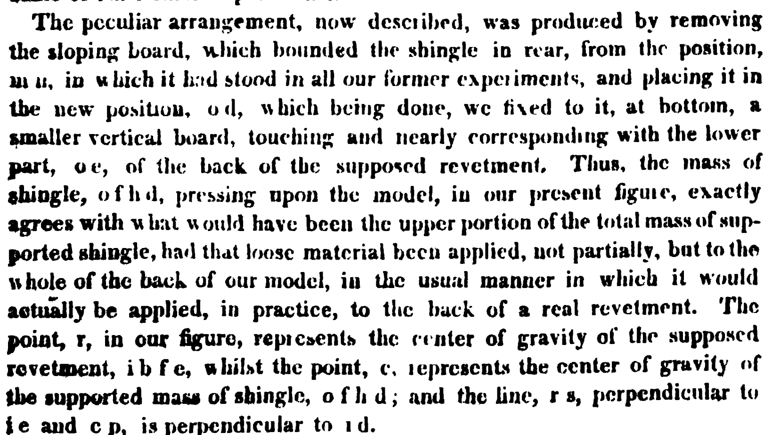
But the very erroneous nature of this part of Mr. Tersac's theory, which

favourable effects could have been produced by it. These expe- shall now be taken into consideration.

If we suppose the two revetments, A and B, represented in the

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I have just objected to, will be proved in a still clearer and more convincing light, by the following experiment, which was tried by me with the sloping model, whose height was 26 inches, mean thickness 12 inches, and slope $\frac{1}{5}$th of the height; in which experiment, instead of backing the model with shingle in the usual manner, that loose material was applied to the upper part (o f) only of the supposed revetment, as shewn in the annexed figure, and was raised to the level, h d, of 60 inches above the top of it. The height, e o, of the point o, which represents the level of the bottom of the supported mass of shingle, o f h d, was equal to 12 inches, and was so regulated, that i o, and o d, formed one continued right line, parallel to the natural slope, f h, of the upper part of the supported mass of shingle, as in some of our former experiments.



The peculiar arrangement, now described, was produced by removing the sloping board, which bounded the shingle in rear, from the position, m n, in which it had stood in all our former experiments, and placing it in the new position, o d, which being done, we fixed to it, at bottom, a smaller vertical board, touching and nearly corresponding with the lower part, o e, of the back of the supposed revetment. Thus, the mass of shingle, o f h d, pressing upon the model, in our present figure, exactly agrees with what would have been the upper portion of the total mass of supported shingle, had that loose material been applied, not partially, but to the whole of the back of our model, in the usual manner in which it would actually be applied, in practice, to the back of a real revetment. The point, r, in our figure, represents the center of gravity of the supposed revetment, i b f e, whilst the point, c, represents the center of gravity of the supported mass of shingle, o f h d; and the line, r s, perpendicular to i e and c p, is perpendicular to i d.

To apply Mr. Tersac's theory to the circumstances represented in our

annexed figure (*See page* 637), to be exactly equal to each other in height, mean thickness, &c., and each to be backed with loose shingle as counterscarp revetments: and, if we further suppose, that the shingle

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present figure, the power of the model to resist the pressure acting upon it ought to be in proportion to the area of i b f e, multiplied into the lever, i s, and also into the specific gravity of the supposed masonry; whilst the power, exerted by the mass of shingle to overset it, ought to be as the area of o f h d, multiplied into the lever, c q, and into the specific gravity of shingle. But it was before stated, that in all our experiments the weight of the models used was 84 lbs. per cubic foot, whilst that of the shingle was 89 lbs. And it therefore follows, that according to the above theory, the stability or resisting power of the supposed masonry, in our present profile, ought to be as the area of i b f e × i s × 84: whilst the oversetting power of the shingle ought to be as the area of. o f h d × c p × 89.

Now, on reducing these proportions to numbers, by calculating in conformity with the dimensions before stated, it will be found that, according to Mr. Tersac's theory, the resistance of the supposed masonry ought to be as 222 928, whilst the oversetting power of the shingle ought to be as 530,139; which proportions reduced are as the numbers 181, and 430, nearly. And consequently, as the latter number is about $2\frac{1}{2}$ times greater than the former, it follows, that when the attempt was made to back the supposed revetment with shingle, to the height, d n, in the manner represented in our figure, the model ought to have had no stability, or power of resisting so great a mass as o f h d, but ought to have overset, in consequence of the pressure acting upon it, long before the shingle was raised to so high a level.

The actual result, however, of our experiment, which shall now be described, was very widely different. For, whilst the average original stability of our model, before any shingle was applied, was found to be equal to 181 lbs.; the average stability of the same model, when loaded with the mass of shingle, o f h d, proved to be no less than 173 lbs. Hence the original stability of our model, was to its stability, when backed with the above mass of shingle, as 181 to 173, as was ascertained by the average of seven very accurate sets of trials; whereas, according to Mr. Tersac's theory, the above proportion ought to have stood as 181 to less than nothing; it being, of course, from the above calculation, as 181 to −249. It would, therefore, be superfluous for me to say any thing further in confutation of such a theory. I shall only remark, that, in the present instance, I adopted the peculiar mode above described, of estimating the weakening power of the upper portion of the supported earth, pressing upon a revet-

pressing upon the first revetment, A, is unmixed with any other material, but that the shingle, pressing upon the second revetment, B, is divided into four several horizontal layers or strata, by three

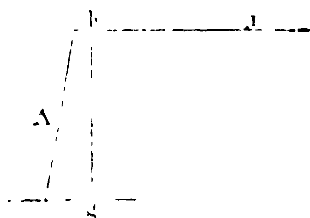
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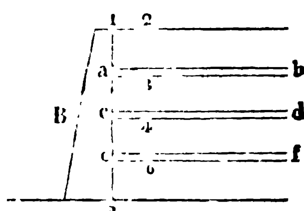
ment; not that I consider it so accurate as the former mode generally used by me for the same purpose, and described in the preceding chapter; but because the results, afforded by the present method, differ less from Mr. Tersac's hypothesis; and therefore, in controverting his doctrines by experiment, I was willing to use that process, which was the least unfavourable to them.

It is true, that Mr. Tersac does not give the above theory as conclusive, nor even the hypothesis, upon which it is founded, as being strictly accurate; but states, that he considers it merely as an approximation to the truth, in a very intricate subject, which, by making the pressure of loose earth rather more powerful, than it would be in reality, may, he conceives, be trusted to as a safe guide in practice. And he even lays down afterwards another theory, founded on a different view of the subject, upon which, or on a combination of the two, it is stated, that he composed tables of revetments, which have not, however, been copied into Colonel Maynier's work. As to the hypothesis, brought forward in Mr. Tersac's second theory, which is not very clearly explained in the above work, it seems to bear no similarity, whatever, to any thing advanced by me, in the preceding chapter; and, therefore, it would be superfluous to notice it, particularly, as he has not attempted to support any of his ideas by experiment, which is, I conceive, the only mode of stamping a value upon such speculations.

In the same book are related a number of experiments, tried by the author (Colonel Maynier) himself, in concert with some other French engineers, with a view to investigate the pressure of earth and sand upon revetments, but which, I must confess, appear to me to prove very little; since those, on which he lays the greatest stress, and to which he chiefly trusts for the support of his own favourite theory, were tried, not with any solid body or bodies, in the shape of or acting like revetments, but with a vertical plane of woodwork, resembling a common window shutter, moveable on hinges at bottom, and deriving no stability whatever, either from its weight, considered as a mass, or from its base, it having none. Five of the experiments made by him were, however, conducted in a manner more likely to have led to some useful conclusion, having been tried with walls of brick and mortar, each about 4 feet 11 inches long, and 3 feet 9 inches high, which he backed with very loose sand, &c., under various circum-

intermediate courses of any solid substance, such as woodwork; then the quantity of shingle, supported by and pressing upon the back of the revetment, A, will be represented by the right angled triangle, g h i, whilst the quantity of shingle pressing upon the back of the revetment, B, will be represented by the sum of the four





small right angled triangles, a 1 2, c a 3, e c 4, and 5 e 6. The height of each of these small triangles will be rather less than one fourth of g h, but if, for the sake of clearness, we suppose that proportion to hold good, the sum of all the small triangles will be to the large triangle, as four times the square of 1 to the square of 4, or in other words, as 4 to 16: and, consequently, the pressure

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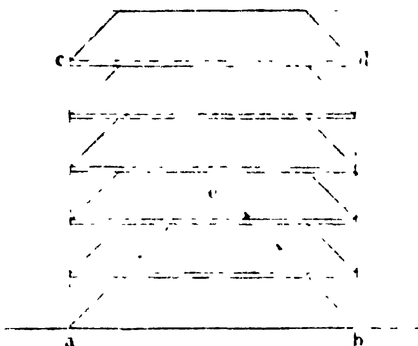
stances, until they overset. Four of these walls were rectangular; 2 of which had a thickness equal to about $\frac{8}{32}$ parts of their height; 1 had a thickness equal to about $\frac{9}{32}$ parts of its height; and another had a thickness equal to $\frac{1}{8}$ parts of its height. The remaining wall was countersloping, with two offsets in rear, and had also an exterior slope of $\frac{1}{10}$th, its mean thickness being equal to about $\frac{8\frac{1}{2}}{32}$ parts of its height. On referring to the work, now quoted, it will probably be allowed, that these five last-mentioned trials with brick walls were too limited in their nature, to throw much light upon the subject of revetments; and that the other experiments, made by Colonel Maynicl, which I before alluded to, are still less conclusive.

With respect to the experiments, recorded by him, as having been tried by former French writers upon the same subject, they appear to have been done with so little variety of circumstances, and in general on so very diminutive a scale, as to be absolutely nugatory.

I have myself in view some further experiments on revetments, which I shall probably try at my leisure.

of shingle upon the back of the revetment, B, is only equal to one fourth part of the pressure of shingle upon the revetment, A.

With a view to ascertain the point now under discussion, I caused the following experiment to be tried: a mound was formed of layers of loose earth, intermixed with woodwork, in the manner shown in the annexed figure. The base of the mound was 11 feet 6 inches square. The horizontal courses of woodwork were placed at intervals of 2 feet apart, and were formed of 1½ inch planks, connected together by ledges of the same thickness.* By this means we were enabled to carry up the mound to



the height of about 13 feet, making the dimensions of it near the top, at c d, equal to the base, a b; and it is evident, that by the same process, we might have raised it almost to any given height. But if we had used only loose earth, without interposing courses of a solid material, at certain intervals, to break the continuity, it would have been impossible to raise our mound higher than about 6 feet from the ground, at which height it would have terminated in a point, forming a kind of square pyramid, the section of which is represented by the triangle, a e b. An inspection of this last figure will clearly prove, what I before asserted, that the four small triangles, a 1 2, c a 3, e c 4, and 5 e 6, are a true repre-

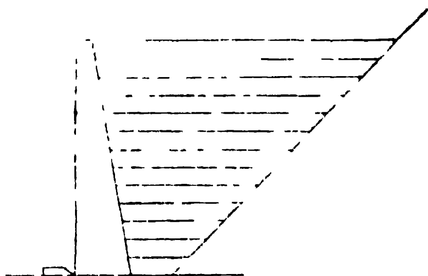
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* In order to save expense, we used pontoon chesses in this experiment, which was conducted by Mr. Nairne Forbes, of the Honourable East-India Company's Engineers, then doing duty at Chatham under my command, with the rank of Ensign.

sentation of the total quantity of shingle pressing upon the back of the revetment, B, shown in our former figure.

But it is not absolutely necessary, in order to produce the effect of greatly diminishing the pressure on the back of a revetment, that the intermediate substance, which breaks the continuity of the loose particles of the supported mass, should be an inflexible body, like strong woodwork; for the same object may be attained, to any required degree, by using flexible substances, such as canvass, thin layers of brushwood, &c. as we ascertained by the two following experiments, both of which were tried with the countersloping model, 52 inches high, having a mean thickness of 8 inches, and a counterslope of one fifth.

On applying shingle to the back of the above model, in horizontal layers of four inches in height, divided from each other by courses of canvass,* in the manner represented in the annexed figure, the stability of this profile, as a counterscarp revetment, proved to be 54 lbs; its original stability before the shingle and canvass were applied being 62lbs., so that the loss of stability, occasioned by the pressure of shingle thus applied, may be estimated at 8 lbs. which is in the proportion of about ⅛th only of the original stability.†



Afterwards we applied the shingle to the same model, in layers of 4 inches as before, but using courses of small loose twigs not

* We used empty sand-bags for this purpose.

† In three several trials with shingle and canvass, the stability was successively 44, 57, and 61 lbs.; the average being 54 lbs.

exceeding half an inch in diameter, to break the continuity of the pressing material, in the manner represented in figure B, which being done, the stability of the profile proved to be 49 lbs.; so that in this case, the loss of stability may be estimated at 13 lbs. which is in the proportion of about ¼th of the original stability.*

Hence it appears, that this model is fully strong enough for a counterscarp revetment, for supporting shingle, or any similar perfectly loose material, provided that the latter is divided into separate horizontal layers, by the insertion of intermediate courses of any other substance, such as planking, canvass, or brushwood, which is capable of breaking the continuity of the pressing material. Now it was proved by one of our former experiments (*See Table* XI, *Experiment* 345), that the same model had no stability whatever, as a counterscarp revetment, when the shingle was applied to the back of it, undivided by courses of any other substance; and therefore it will be evident, that the various expedients, now under discussion, may be used to great advantage to diminish the pressure of loose earth upon revetments; which having hitherto been generally considered an object of great importance, almost all writers upon practical fortification have accordingly recommended brushwood for this purpose, as being the cheapest expedient that can be adopted.

There are three ways, in which the above material may be used in consolidating the terrepleins of reveted works; first, by applying it in the form of regular fascines, which need not exceed six inches in diameter; secondly, in the form of hurdles; thirdly, by merely spreading it loose in courses, not exceeding three or four inches in depth. Whichever method is used, the courses, whether of fascines, hurdles, or branches, may be placed at intervals of from three to four feet

* In three several trials with shingle and twigs, the stability was successively 58, 44, and 45 lbs.; the average being 49 lbs.

apart: and instead of laying them quite horizontal, they may have a gentle fall towards the rear, to carry off the rain-water which may soak through from above, and prevent it from lodging against the back of the wall. Fascines were generally used by the French Engineers in forming the terrepleins of their fortresses, during the reign of Lewis the Fourteenth: branches were adopted in preference, in constructing the ramparts of Portsmouth; and the latter must certainly be allowed to be a better method, for after the wood rots, which must be expected in course of time, the mass of the terreplein will eventually, in this case, have more consistency, than in the former.*

As the intermixture of any perishable material, can evidently only cause a temporary diminution of the pressure of earth upon a revetment, it certainly would not be prudent to adopt a weaker profile, on this account, than would be required, if no such expedient were used. In building a fortress, no diminution of the masonry can therefore arise from the use of brushwood, which may accordingly be rejected as a superfluous expedient; but in the parapets of field works, constructed in loose soil, it may be of great advantage.†

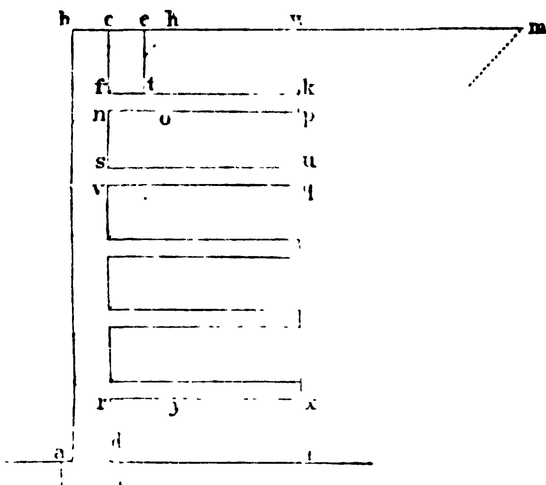
But the principle of breaking the continuity of the supported earth, although useless and ineffectual for permanent purposes, if any perishable material is employed, may in many cases be applied to advantage, so as to produce the desired effect of saving expense,

* Hurdles are best of all. They are more compact than branches, and occupy much less space than fascines.

† In besieging the Castle of Santa Maura in 1810, there being no earth on the spot, shingle was used for the batteries, which was intermixed with brushwood laid horizontally, and also with fascines, used as headers, running through the whole mass at central intervals, by which means it was found practicable to complete the necessary revetments with fascines, the common method of securing them by pickets alone, without these additional precautions, having previously failed.

provided that masonry itself, or any other durable substance, connected with the body of the revetment, is used for that purpose.

To explain the mode of construction, now alluded to, let us suppose a b, in the annexed figure,* to represent the exterior surface of a revetment, and that it has counterforts at certain intervals, which instead of being built independent of each other, according to the usual system, are connected by five tiers of arches, which appear in section in the figure, but two of which only, f k n p, and s u v q, are lettered, to prevent confusion. Then it will be evident, that, if the revetment, thus constructed, is backed with loose shingle or earth, the five tiers of arches will produce the effect of breaking the continuity of the pressing material, so that instead of being equal to the great triangle, d c m, the quantity of pressure acting upon the back, c d, of the revetment, will be represented by the sum of six small triangles, shown in the figure, of which, f c h, is the uppermost, and d r y, the lowest. Now if we suppose the revetment, a b c d, to be of such a thickness, that the pressure of the small triangle, f c h, is incapable of breaking down



* This and some of the following figures, although referring to dimensions actually specified, have been drawn rather out of proportion, for the sake of clearness.

the portion of masonry which is immediately in front of the line, f c, and that the pressure of the small triangle, s n o, is incapable of breaking down that portion of masonry which is in front of the line, s n, and that, in like manner, the pressure of each of the other four small triangles is incapable of breaking down that portion of the revetment, upon which they respectively act; it follows, of necessity, that the whole weight of these triangles must press vertically downwards; and consequently not only the mass of shingle, represented by the trapezoid, f h w k, but also that, which is represented by the triangle, f c h, or, in other words, the whole of the shingle contained in the space, f c w k, must press vertically downwards upon the crown, f k, of the highest arch represented in our figure, provided that the upper part of the revetment has such a thickness, as not to admit of its being torn asunder by the lateral pressure of that portion of the same mass, which acts upon it.* Now it must be evident, that the revetment cannot possibly be overset upon the pivot, a, without raising the arch, f k, during this movement, to a much higher level, and therefore the weight of shingle contained in the space, f c w k, opposes not only the rise of the arch, but also the fall of the revetment, with its whole weight;

* If the lateral pressure of any loose material is not capable of tearing asunder the obstacle, which resists it, it must of course become dormant for the time being. Thus in the body of a waggon, whose sides are removed, it will be evident, that coals, although a loose material, may be piled up perpendicularly, to any required height, provided that they are previously inclosed in sacks, and built in regular horizontal courses like masonry. Now under this supposition, it must be allowed, that the lateral pressure of the loose coals, acting upon and resisted by the inclosing canvass, does not in the least degree diminish any part of the vertical pressure arising from their weight, the whole of which is supported by the body of the waggon. Yet at the same time, the lateral pressure, although dormant, is not done way, for if any of the exterior sacks were cut, it would immediately come into action, and cause the loose coals to rush out through the aperture.

and in like manner the shingle contained in the space, s n p u, by acting on the crown, s u, of the arch below, opposes also the fall of the revetment with its whole weight; and in short, the same doctrine holds good in respect to all the other arches, which are acted upon by similar masses of shingle, and with a similar tendency of adding stability to the revetment.

Reasoning thus, it will appear, that the whole mixed mass of shingle and masonry, represented in section by the figure, a b w i, combines together in resisting the pressure of that portion of the supported triangle of loose shingle, d c m, which has a tendency to overset the revetment: and therefore, if we suppose the specific gravity of the shingle and masonry to be equal, the said mixed mass will, as a revetment, have very nearly as much stability, as if the whole of the space, a b w i, which represents the extent of it, were composed of solid masonry. Hence may easily be determined, under any given circumstances, the dimensions proper for A COUNTERARCHED REVETMENT, which is the term used to designate the profile represented in our present figure, in contradistinction to the other kind of revetments, treated of in the preceding chapter, which are called SIMPLE REVETMENTS.

For example's sake, I have supposed the counterarched profile, a b w i, to be a rectangle, on account of clearness, although any other form, sloping, leaning, or countersloping, might have been chosen for the same purpose. By Experiment 124, Table V, it appears, that a rectangular revetment, whose thickness is equal to three thirteenths of the height, with counterforts also equal to three thirteenths of the height in length, possesses sufficient stability as a counterscarp revetment.* Now the total

* In the casemated work recently constructed at South-sea Castle, near Portsmouth, the thickness of the counterscarp revetment, which is rectangular, is equal to one fourth of the height: the counterforts are square, and also equal in length to one fourth of the height, and placed at central intervals of four times their width apart. The proportions of this profile, which was

depth of masonry, in the rectangular profile, which has just been stated, if measured in section through one of the counterforts, is equal to six thirteenths of the height. In determining the dimensions of our counterarched profile, a b w i, we cannot therefore well allow less, than the above proportion; on the contrary, as the actual mass of masonry will be much less than that of the simple profile in question, it will be prudent to make the depth of it rather more than six thirteenths. We shall accordingly suppose the lines b w, and a i, which represent the said depth, to be each equal to one half of the height, a b, in which case the strength of the two profiles under consideration will probably be nearly equal.

Now, to reduce the matter to fixed dimensions, if we suppose the height, a b, to be 100 feet; and that the five arches are each 2 feet thick, which is as substantial as can possibly be necessary, the six spaces, c f, n s, r d, &c., into which the supported shingle is divided, will each be 15 feet high, and this will of course determine the value of the various pressing triangles, f c h, s n o, &c., acting on the back of the revetment. But it has been proved by Experiment 43, Table II, that a rectangular profile without counterforts, whose thickness is equal to one third of its height, is sufficiently strong for resisting the pressure of shingle, as a counterscarp revetment.* Accordingly, the thickness

backed with shingle, so very nearly agree with those of the similar rectangular profile, mentioned in the text, the difference of mass in proportion to their respective heights being only as 12 to 13; that it appeared proper to introduce it, partly as affording some support to my experiments, and partly because the counterscarp revetment, which I have just described, and which I believe is about 11 feet high, is the only instance, to my knowledge, of a rectangular profile having actually been executed.

* In the experiment alluded to, the thickness was equal to four thirteenths of the height only, which is a little less than one third: therefore the latter proportion will be ample, for the revetment of our counterarched revetment; particularly as it derives great additional stability from the piers and arches, that are united to it.

at top and bottom, b c, and a d, of our supposed revetment, may be made equal to 5 feet, which being done, it will be impossible for it to be broken down, in any part, by the pressure of the various triangles, that act immediately upon the back of it, the height of each of which is 15 feet, as was before stated. This being determined, the depth of the arches (f k, s u, &c.) and the length of the counterforts, which serve as piers for supporting them, will of course be 45 feet, the total depth of masonry, b w, or a i, being equal to 50. With respect to that part of the revetment, which is above the uppermost arch, it is already nearly strong enough; but, by way of further precaution, we shall allow it counterforts 6 feet long, one of which is shown in the figure, by the rectangle, f c e t. The piers or counterforts, may be about 3 feet wide, with central intervals of 18 feet, which is six times their width, and which will allow a clear space of 15 feet, for the span of each arch. Segment arches of uniform thickness throughout, and rather flat, having a rise, for example, of about 2 feet 6 inches, which is in the proportion of one sixth of their span, will be the most convenient. The perpendicular height of the lowest arch above the level of the base, a i, of the revetment, may be 13 feet 9 inches, at the spring, and 16 feet 3 inches, at the crown, so that its mean height above that level will be 15 feet, according to our former supposition.

Such being the dimensions of our supposed counterarched revetment, it will be found, by calculation, that the quantity of masonry, contained in this profile, including the revetment, with the counterarches and their piers, and the counterfort above them, will be very nearly equal to that of a simple wall without counterforts, of the same height, and having a mean thickness of about 15 feet 7 inches.*

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* The rough estimate, from whence this conclusion was drawn, is as follows,

The area of the revetment, a b c d, as it appears in the section, is $= 100 \times 5 = 500$ superficial feet.

The area of one arch, n f k p (or v s u q), as it appears in the section, is

Now, according to the seventh rule, given in the preceding chapter, a simple counterscarp revetment, countersloping at one fifth, ought to have a mean thickness of $\frac{1}{4}$th of its own height, besides counterforts, adding to the mass of masonry, in the proportion of a continued wall having a mean thickness of one twenty-fourth part of the height; and consequently the mean thickness of a simple wall

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$= 45 \times 2 = 90$. There being 5 arches, multiply by that number, and $90 \times 5 = 450$ superficial feet for the whole. If the arches were flat, the above would be a just estimate, but in consequence of the curve, about one fifteenth part more must be added. $450 + \frac{450}{15} = 480$ superficial feet, will therefore represent the true value of the five arches.

The area of one pier, d r x i, is $= 45 \times 15 = 675$. There being 5 piers, multiply by that number, and $675 \times 5 = 3375$ superficial feet, will give the area of the whole, as they appear in the figure; but as the masonry of the piers occupies only one sixth part of the space in rear of the revetment, the above value must be reduced in proportion, and accordingly $\frac{3375}{6} =$ $562\frac{1}{2}$ superficial feet, will give the true estimate of the piers.

The area of the counterfort, f c e t, above the uppermost arch, is $= 6 \times 15 = 90$, of which, for the same reason, that applied to the piers, one sixth part $= \frac{90}{6} = 15$ superficial feet, must be taken for the true value.

Recapitulation.	*Superficial feet.*
The revetment - - - - - - -	500
The five arches - - - - - - -	480
The five piers - - - - - - -	$562\frac{1}{2}$
The counterfort - - - - - -	15
Total value of masonry in the section - -	$1557\frac{1}{2}$

Hence, as the height of the profile is 100 feet, the above result must be divided by that number, and the quotient will be equal to 15·575, or to 15 feet 7 inches nearly; which accordingly shows the mean thickness of a simple wall, without counterforts, of the same height, equal, in quantity of masonry, to the counterarched revetment, represented in our figure.

equal to a revetment and counterfoits so proportioned, if calculated according to the above rule, is 29 feet, 2 inches.

The quantity of masonry, contained in the counterarched profile now under discussion, will therefore be, to that contained in my countersloping profile, in the proportion of $15\frac{1}{2}$ to $29\frac{1}{6}$ nearly, being only about one half of the latter; and thus it appears, that by a judicious application of the principle of breaking the continuity of the supported mass, a counterarched revetment may be built, equal in stability to a simple revetment, in which this principle cannot be applied, and at the same time, with a great saving of masonry, that is to say, in very high profiles, such as we have just taken for an example: for in lower profiles the saving will be less considerable,* and when the height is so much reduced as to be under 20 feet, the common simple revetment, of the nature described in the preceding chapter, requires so small a quantity of masonry, to support the retained earth, that for a reason there stated, it may seem rather expedient to augment, than to endeavour to diminish it.

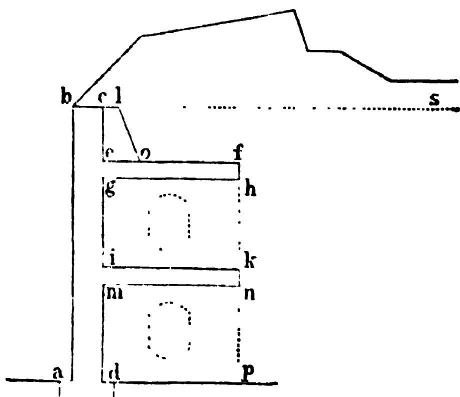
In the example of a counterarched profile, which has just been given, the supported earth was not raised higher than the level of the top of the revetment, and therefore the total depth of masonry was made equal to half the height only, a proportion

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* This principle cannot be effectually applied to low revetments, for a sufficiently obvious reason. If we supposed, for example, our counterarched profile, represented by the figure a b w i, to be 20 feet high only, instead of 100, and that the other parts were reduced in like proportion, the thickness of the revetment would be 1 foot, the height of the piers and counterforts would be 3 feet, their width being $7\frac{1}{2}$ inches; the span of each counterarch would be 5 feet, and its thickness or depth not quite 5 inches. Such arches and walls would evidently, from the minuteness of their parts, be ridioulous, as they could neither have consistency nor durability; and yet, unless so constructed, it will be equally evident, that a proportional saving of masonry cannot be obtained.

which will suffice for counterscarp revetments, in case this principle were applied to them; but when it is applied to demirevetments, or partial scarp revetments, it will of course be proper to make some addition to the mass of masonry used, and accordingly, $\frac{5}{12}$ths of the height may be chosen, as a proper dimension for the total depth.

If therefore, in the following figure, we suppose the principle under consideration to be applied to a scarp revetment of thirty feet, which is a good height for that of the main inclosure of a fortress; we may allow 3 feet 6 inches for the thickness, b c or a d, of the revetment. The arches, g e f h, and m i k n, will be each 14 feet long, and may be 1 foot 6 inches thick. The piers, d m n p, and i g h k, will also be 14 feet long, and may be 10 feet 6 inches in mean height. This will leave 6 feet for the height, e c, of the counterfort, which may be 3 feet long, that is to say in mean length, for it may be made countersloping, in the manner shown by the trapezoid e c l o. The piers and counterforts may be 3 feet thick, and placed at central intervals of 18 feet apart, as in the last example.



Calculating according to these dimensions, it will be found, that the supposed counterarched scarp revetment, 30 feet high, represented in our figure, will be equal in quantity of masonry to a simple wall of the same height, having a mean thickness of 6 feet

$8\frac{3}{4}$ inches;* whilst the simple countersloping profile of the same height, recommended by me in the preceding chapter, including its counterforts, is equal to a wall having a mean thickness of 10 feet, if used as a full scarp revetment; but if used as a partial scarp revetment without a berm, it is equal to a wall having a mean thickness of 10 feet 6 inches. *(See Tables* A *and* B, *in pages* 628, *and* 629.) Thus by adopting a counterarched scarp revetment, in preference to a simple one, there may, in a height of 30 feet, be a saving of rather more than one third of the total quantity of masonry.

It will be evident, that there might result a still greater economy of materials, and yet little or no diminution of stability, in the counter-arched profile, by building the counterforts hollow in certain parts, and connecting the vacant spaces thus formed by arches, as represented by the dotted parts of the figure, in the last section; but unless the piers were of very extraordinary length, as in our first

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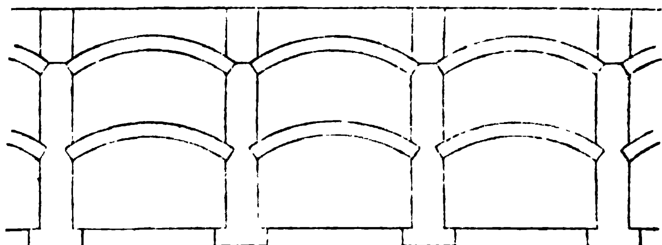
* The rough estimate is as follows.

Revetment $30 \times 3\frac{1}{2} =$ - - - - - - - - - - - -	105
Arches 2 (each $= 14 \times 1\frac{1}{2}$) = - - - - - - - - -	42
Add one fifteenth part of the above for the curve $= \frac{42}{15} =$	2·8
Piers 2 (each $= \frac{10\frac{1}{2} \times 14}{6}$) = - - - - - - - -	49
Counterforts $= \frac{6 \times 3}{6} =$ - - - - - - - - - -	3
Total superficial feet - - - - -	201·8

Hence the mean thickness of a simple wall without counterforts, equal to the above, will be $= \frac{201\cdot8}{30} = 6\cdot726$ feet, or by reducing the decimal, to 6 feet $8\frac{3}{4}$ inches nearly.

example, it would scarcely be worth while to have recourse to this expedient.

As a further illustration of the nature of a counterarched revetment, I annex a figure, representing the rear elevation, of the



masonry work only, of one constructed with two tiers of arches, which will therefore correspond with the transverse section of the masonry of the supposed scarp revetment, shown in our former figure.

I shall next apply the principle, now under consideration, to a counterscarp revetment, which shall be supposed to be 22 feet high, and which might also be represented by the last section, (*See page* 649), provided that all above the level of the horizontal line, b s, were cut off. In this case, I would allow the thickness (b c, or a d) of the revetment to be 2 feet 8 inches; the depth (f h, or k n) of the two arches to be 1 foot 3 inches, and their rise to be 2 feet 3 inches; the length of the arches and of the piers (g h, or m n) to be 8 feet 4 inches; the mean length of the counterfort to be 3 feet; its width and that of the piers to be 2 feet 8 inches; and their central intervals to be 16 feet, which is 6 times their width; and the mean height of the piers (i g, or d m) to be 8 feet.

By using this profile, it will be found, that there will be a saving of about three eleventh parts of the quantity of masonry, that

would be required for my simple profile of a counterscarp revetment of the same height.*

Lastly, as an example of the mode of counterarching a lower counterscarp revetment, I shall suppose the height to be only 15 feet. In this case one counterarch may suffice, which may be 1 foot 3 inches thick, 8 feet in mean height above the base of the revetment, and 5 feet 4 inches long; which will also determine the length of the piers. The thickness of the revetment, and that of the piers and counterforts to be each 2 feet 8 inches, the span of the arches to be 13 feet 4 inches, and their rise 2 feet 3 inches, all of which particulars are the same as in the last example.

Using these dimensions, it will be found by calculation, that the counterarched counterscarp revetment of 15 feet, which has been described, will require fully as much masonry, as is necessary to enable my simple countersloping revetment with coun-

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* The rough estimate is as follows,

Revetment $22 \times 2{\cdot}666 =$ - - - - - - - - - -	58·6666
Arches 2 (each $= 1{\cdot}25 \times 8{\cdot}333) =$ - - - - - -	20·8333
Add one fifteenth part of the above for the curve $\frac{20{\cdot}8333}{15} =$	1·3888
Piers $2\left(\text{each} = \frac{8 \times 8{\cdot}333}{6}\right) =$ - - - - - - -	22·2222
Counterfort $= \frac{3{\cdot}5 \times 3}{6} =$ - - - - - - - - - -	1·75
Total superficial feet - - - -	104·75

Hence the mean thickness of masonry of a simple wall without counterforts, equal to the above, will be $= \frac{104{\cdot}75}{22} =$ 4 feet 9 inches nearly: but the mean thickness of a wall equal to my countersloping counterscarp revetment with its counterforts, of the same height, is = 6 feet, 5 inches (*See Table* C, *page* 630); so that the former may be built with about three eleventh parts less masonry, as stated in the text.

terforts of the same height, to resist the pressure of earth acting upon it.*

Hence it appears, that in low revetments, the saving of masonry to be obtained by adopting a counterarched profile, is inconsiderable or null. It is true, that the dimensions of the several revetments might have been still further reduced, in the above examples, by giving to the various portions of the back of each a counterslope in rear; instead of making the whole of uniform thickness from top to bottom; but as I must again repeat, the reduction of the mass of walls, below a certain limit, is to be reprobated. Even in those cases, however, in which there may not be a diminution of masonry, the counterarched profile may no doubt sometimes be preferable to any of the simpler forms, under certain circumstances, the determination of which must be left to the judgment of the Engineer employed. Like the countersloping profile, it has the great advantage of being perpendicular exteriorly; and as far as regards military works, experience has proved, that it is more difficult to effect a practicable

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* The rough estimate of the counterarched revetment is as follows:

Revetment $15 \times 2{\cdot}666 =$ - - - - - - - -	40
Arch $= 1{\cdot}25 \times 5{\cdot}333 =$ - - - - - - - - - - - -	6·6666
Add one fifteenth part of the above for the curve $= \frac{6{\cdot}666}{15} =$	0·4444
Pier $= \frac{8 \times 5{\cdot}333}{6} =$ - - - - - - - - - - - -	7.1111
Counterfort $= \frac{5{\cdot}75 \times 3}{6} =$ - - - - - - - - - -	11·5
Total superficial feet - - - - -	65·6111

Hence the mean thickness of masonry of a simple wall without counterforts, equal to the above, will be $\frac{65{\cdot}6111}{15} = 4$ feet $4\frac{1}{2}$ inches nearly, whilst the mean thickness of a wall equal to my countersloping counterscarp profile and its counterforts, of the same height, is also 4 feet $4\frac{1}{2}$ inches (*See Table* C, *page* 630).

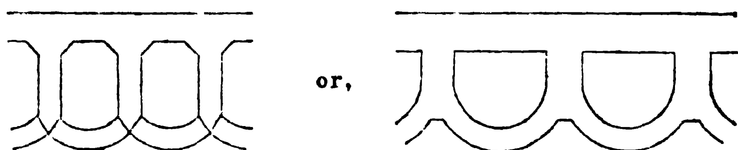
breach in a counterarched scarp revetment, than in any other.* With respect to the workmanship of the arches used in this kind of profile, it will not be so expensive, as that of common arches for other purposes; because in works built of stone, irregular long stones may be selected and used, without the trouble of cutting them by a mould; and in all cases, wooden centering may be dispensed with, by carrying up the rammed earth, in the various chambers beneath each tier of arches, to the proper height, before these arches are begun; and giving to it, at top, a form corresponding to the proposed curves. As we know, by experience, that excavated earth may be compressed into a smaller space, than it originally occupied in its natural state

* Counterarched revetments were recommended by Castriotto an Italian, and Speckle a German engineer, the latter of whom died in 1589; and were adopted about or soon after that period, in the construction of several fortresses. In the siege of Dillemburgh in Germany, in the seven years' war, more than usual difficulty was experienced in breaching the revetments, which were constructed according to this system. In the siege of Badajoz, in Spain, when attacked by the British in 1812, the piers and arches of a casemated flank proved a great obstacle to the effect of the breaching guns, that were directed against it.

The Cotonera works, in Malta, planned by Valperga, a Piedmontese, about the year 1610, the main inclosure of which only is finished, have a counterarched scarp revetment, which in some parts is of extraordinary height; one curtain being, to the best of my recollection, not less than 80 feet high. Some of the chambers, formed by these counterarches, are filled with rubbish: others still remain empty, and have been fitted up as a kind of casemates, although evidently, they could not originally have been intended as such. These works are remarkable for the apparent disregard shown to the nature of the ground, which has been the cause of the great height to which some parts of the profile have been elevated: but a still more striking instance of the same neglect is observable, in a project for fortifying Rabato, the capital of the island of Gozo, drawn up by the same person, who, although the situation is totally unfit for a fortress, proposed to occupy it by an extensive regular polygon, the outline of which would inclose the base of a hill on which the town is built, and which if it had been carried into effect, would have been plunged into, at the distance of about 150 yards, by another higher hill opposite, at the foot of which his works would lie.

in the ground, there is no likelihood of the earth settling, so as to leave vacancies beneath the counterarches of revetments, so constructed, provided, that it is properly rammed during the execution of the work; nor indeed would such settlement, if it actually took place, be a matter of any importance, as it could be attended with little or no prejudice to the strength of the profile.

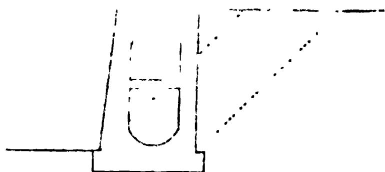
Another mode of increasing the base, and thereby the stability of revetments, without augmenting the mass of masonry to that degree, that would be necessary in a simple profile, has also been recommended; which is by building the revetment hollow at certain intervals, and afterwards filling these empty spaces with earth or rubbish, or any other material, cheaper than masonry. In laying down rules for this mode of construction, vertical counterarches, abutting either against the rear of the front part of the revetment, or against piers or counterforts projecting from it, have usually been recommended, so that the cells or cavities, left in the masonry, do in some part of them resemble niches or upright segments of a hollow cylinder, as may be understood by the annexed figures, which represent a plan or rather a horizontal section of revetments, so constructed, and in both of which the upper line is supposed to denote the exterior surface of the wall.



As far as regards the general section of such works, it will be evident, that it may be either rectangular, leaning, sloping or countersloping. In most cases it will be best to connect the whole of the masonry into one mass, by forming rather flat inverted arches, under each cavity, so as to constitute one continued foundation of solid masonry. If the cells were circular or semicircular

in their outline, and consequently cylindrical or semicylindrical in their general form, these arches might be constructed like inverted domes, or half domes; but if the outline of the cavities themselves is not regular, the inverted arches must also necessarily be irregular.

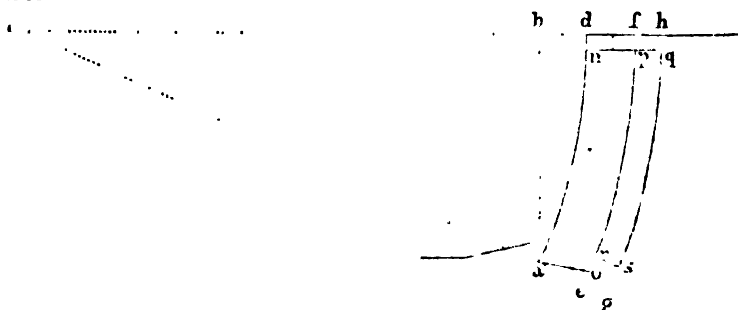
In addition to the above precaution, the CONCAVE REVETMENT, now under consideration, may be further strengthened by running one or two thin horizontal courses of brick-work or masonry, at certain intervals, across the cells, particularly when the latter are to be filled with any loose substance, such as shingle, and it will also be expedient to arch them over at top. The annexed figure represents the section of a revetment, so constructed, in which, provided that the cells are filled with any tolerable heavy material, it will be evident, from the principles before laid down, that the stability of the profile, as opposed to a pressure in rear, will be very nearly equal to that, which would be obtained, by building the whole mass of solid masonry.



Having found, on applying this principle to a scarp revetment of 30 feet in height, that there was not likely to result any very great saving of masonry, when compared with my simple counter-sloping profile with counterforts, unless the dimensions of the various parts of the supposed concave profile had been reduced smaller, than appeared to me advisable in practice, I shall not attempt to give any detailed examples of it, but shall conclude by remarking, that I do not know of its ever having actually been used in military works, nor do I recommend it for such.*

* The kind of profile, now under description, was proposed, but without any inverted arches, by a French engineer called Charpentier, in 1742; and Colonel Mayniel, in his treatise before quoted, suggests, that if the cells were left hollow, and connected by doors of communication, they might either be useful as a kind of small casemates, or might serve in lieu of

I have now discussed almost every form that has either been actually given or recommended to be given to revetments, with the exception of one peculiar kind of leaning revetment, that has of late been adopted by some of the civil engineers in this country, for the retaining walls of wharfs and wet docks, the back and front of which, as shown in section, are not right lines, but circular arcs.



In the annexed figure, which represents a section of the kind of profile, now alluded to, the general form of the revetment and of its counterforts, is found by describing three concentric arcs, a d, e f, and g h, from a center c, assumed somewhere on the same horizontal level with the top of the proposed work. The length of the radius, c d, of the smallest arc, has usually been from 2½ to

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galleries. But on inspecting the plan and section, given by him, as an illustration of this idea, it appears to me, that for a scarp revetment, the usual disposition, adopted in common casemates, is much preferable; and even for a counterscarp, if for any reason a continued gallery of the usual form were rejected, I would, in preference to the scheme alluded to, build a range of chambers, exactly resembling small casemates, and roofed as such by common arches, excepting that in rear I would connect the piers, not by a wall carried on in one continued right line, but of a curved form, so as to oppose a vertical counterarch to the pressure of earth.

The only instance, to my knowledge, of a concave revetment being actually executed, is one now building in his Majesty's dockyard, at Sheerness, under the direction of Mr. Rennie, which shall be described in a future note.

3 times the total perpendicular height, a b. The thickness of masonry, of the revetment d f, has generally been made in some ratio, between one fourth and one fifth of the said height; and the length and width of the counterforts have generally been equal to about one ninth part of the same, their central intervals being 18 feet. The summit of the revetment has usually been crowned by a course of large coping stones, as shown in the figure, below which the general level, n p q, of the top of the masonry, has been made nearly horizontal. At bottom, the base of the revetment and counterfort have sometimes been laid out in one continued inclined plane, coinciding nearly with the radius produced, a g, but more usually with a somewhat smaller degree of obliquity, that is to say in an inclined plane approaching more nearly to a horizontal level. Sometimes the base of the revetment and that of the counterfort have been laid out, not in one continued plane, but in such a manner as to form two different inclined planes, nearly parallel to each other, both deeper in rear than in front, and of the same depth in rear, as represented by the lines, a o, and r s, in our figure. Sometimes again the front part of the base of the masonry only has been laid out according to an inclined plane, such as, a o, whilst the remainder of it, from some given point, such as, o, backwards, has been laid out horizontally: but in no case, has the base of the masonry ever been made horizontal throughout.

The wharf walls of the West-India Docks, which I believe were the first specimen of this kind of profile, are constructed nearly in the manner represented by the above figure. Their dimensions are as follows. The radius, c d, of the smallest arc, a d, is 72 feet: the perpendicular height, a b, is 29 feet, including a foundation of about 2 feet deep: the base, b d, of the slope, formed by the exterior curve, is 6 feet; the thickness of masonry, n p, of the revetment is 6 feet; and the counterforts, r p q s, are 3 feet square, and placed at central intervals of 18 feet apart. The general foundation is broken into two inclined planes, a o, and r s.

In the retaining walls of the Limehouse entrance bason, the height, the radius of curvature of the exterior surface, and all other particulars, are the same as above, with the exception of the thickness of the revetment, which is only 4 feet 6 inches; and this last is probably one of the thinnest profiles in proportion to its height, that has hitherto been executed. In both of these examples, the revetment and counterforts were built of brick, the coping only being of stone.*

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* The above works were planned by Mr. William Jessop. I have since seen a section of a wharf-wall of a similar description, and also 29 feet high, proposed, and about to be executed, by Mr. Rennie, which may be understood by a reference to the same figure, and of which the dimensions are as follows: the radius, c d, of the exterior curve is 87 feet, and consequently the base, b d, of the slope thereby formed, is equal to 5 feet nearly. The arcs are concentric, as in the former example, the thickness of the revetment, n p, which is to be faced with very large stones, backed with brick, being 6 feet 6 inches: the counterforts are to be 3 feet 9 inches square, and placed at central intervals of 18 feet; and are to be built of brick, excepting in two places, where they are to be connected to the revetment by binding courses of stone running through the whole body of the work, and placed at equal intervals apart. The foundations both of the revetment and counterforts are in the same plane, which appeared to coincide nearly with the produced radius, a g.

It is to be observed, that, although concentric arcs seem to be the favourite system, they have not always been adopted. For example, in the entrance bason of the East-India Docks, the revetment, which is 22 feet high, and the exterior curve of which is so proportioned, that the base of the slope thereby formed, is no less than 10 feet, is 3 feet 6 inches thick at top and 7 feet 6 inches thick at bottom, the back of the wall being also curved, but described from a different center, as well as by a greater radius. In this work, which was planned by Mr. Walker, the revetment is built of large stones, and the counterforts of bricks. The latter are 2 feet 3 inches wide, and placed at central intervals of about 18 feet apart, and are nearly perpendicular in rear, so that their length varies from 1 foot 6 inches at top, to 7 feet 6 inches at bottom. Their foundation is laid out nearly horizontal, and is of the same depth as the back of the base of the revetment, the latter being an inclined plane, deeper in rear than in front, according to the usual custom.

Upon the CURVED LEANING REVETMENT, which has been described, I shall remark, that its peculiar construction adds greatly to the trouble, and in some degree to the expense, of the workmanship, and therefore appears to me objectionable; the more especially, as I do not see that the least advantage can be derived from the curve, in opposition to a pressure of earth in rear; for, although built in the archlike form, the wall cannot possibly have any strength as an arch, nor can it even, with propriety, be considered as such, since it has only one abutment. Whenever a leaning profile may appear advisable, I should therefore certainly recommend using a simple right-lined section in preference to a curved one, unless the wharf or other wall about to be formed should happen to be exposed to the beat of the sea, in which case a curve may perhaps be considered more advantageous, as being less liable to be injured by the shock of the waves.*

I have already sufficiently stated my opinion, in the preceding chapter, that, of all simple profiles that can be adopted, the countersloping is the best for military purposes;† but although re-

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* Mr. Smeaton, in constructing the Edystone Light-house, which is a round tower, the masonry of which alone exceeds 60 feet in height, and of which the diameter, every where inconsiderable in proportion to the above, is much greater at the base, than in other parts, has laid out the exterior of the work, as it appears in section, not in one continued right line, but with a curve, rather concave towards the bottom, which form, he conceived, would be the best adapted for resisting the break of the sea.

Mr. Telford, in a sea-wall, built by his direction, at Ardrossan, in Ayrshire, in a situation exposed to the Irish Sea, has adopted a CURVED SLOPING PROFILE, that is to say, one curved exteriorly, but perpendicular in rear, to which he has added countersloping counterforts. The base of the revetment is laid out according to an inclined plane; that of the counterforts is horizontal.

† The general tenour of our experiments with shingle seems to prove, that, in thin profiles for retaining loose soil, the countersloping is certainly the weakest. If, therefore, the durability of walls, built with exterior slopes, could be depended upon, I should not have hesitated to recommend,

commended by some recent writers, I am not aware that it has ever yet been used in works of any magnitude.* This opinion, in

for military works, a leaning profile with counterforts, in preference to all others. If used as a partial scarp revetment or demirevetment, a leaning profile having a thickness equal to one fourth of its height, would, I conceive, be strong enough in all cases; whilst, if used as a counterscarp revetment, a thickness of one fifth of the height, only, would suffice; which profiles might of course be built at less expense of masonry, than the countersloping profiles, actually recommended, for military works, in Rules VI, VII, and VIII, and more fully detailed in Tables A, B, and C; and which, upon the whole, all circumstances considered, appear to me to be the best. The counterforts, in both profiles, might be equal.

* M. Gay du Vernon, a French engineer, employed as professor of fortification, at the Polytechnic School at Paris, in a work, published in 1805, entitled, "Traite Elementaire d'Art Militaire et de Fortification," is the first writer, to my knowledge, who has recommended the countersloping profile; but in so doing, he begins by remarking, that it had been already proposed by several engineers, whose names he does not specify. He allows, to his scarp and counterscarp revetments, an exterior slope of one twentieth of the height, and a counterslope in steps, equal to one eighth of the height, so that the additional thickness, gained towards the bottom by this construction, is rather more than one sixth of the height. He varies the thickness at top of his scarp revetment, at different heights, and in the same proportion nearly that was recommended by Belidor, and he allows rectangular counterforts to it, at fixed central intervals, of about 16 feet 4 inches; but he makes his counterscarp revetments, of uniform thickness at top (about 3 feet, 10½ inches) and without counterforts, which I conceive to be a very faulty construction.

The first instance of a countersloping revetment, actually executed, that has come to my knowledge, is the gunwharf wall at Portsmouth, building in 1799 and 1800, which, besides a certain exterior slope, has steps in rear equivalent to a counterslope, but I do not recollect any of the details.

The sea-wall, building at Liverpool in 1806, is a second and more complete example of this kind of profile. It was 30 feet high, 7 feet 6 inches thick at top, and 15 feet thick at bottom, with an exterior slope of one twelfth, and a regular counterslope (without steps) of one sixth of the height. It had counterforts, 15 feet wide, placed at central intervals of 36 feet apart. These counterforts were 27 feet high, and 15 feet long at the base, which length is continued to the height of 15 feet upwards: from thence it is reduced by three successive offsets, nearly equal in width, and at intervals of 4 feet in height, to 4 feet 6 inches, which is the length at

favour of the countersloping profile, is the result of conviction, arising from the experiments made with a view to investigate the subject; for, until these were tried, I must confess that I doubted, whether it would have sufficient strength to render it an eligible profile for practical purposes, notwithstanding the great advantage of its exterior perpendicularity. At that time, there appeared to me good grounds for believing, that a leaning revetment would be found to be the strongest. And, indeed, but for the serious disadvantage attending its exterior slope, this last-mentioned profile would be exceedingly well adapted for works of fortification, because, from its having an uniform thickness throughout, it is more substantial at top, than either the sloping or countersloping revetment, and consequently has a greater power of resisting an enemy's batteries,* for in breaching the revetments of a fortress by cannon, there is no necessity, whatever, for firing at the lower part of the wall; because, when the upper half of a revetment is battered, the stones, or bricks and rubbish, knocked off by the balls, fall down at a considerable slope, and bury the remainder of the wall entirely, forming a practicable ascent throughout. It is, therefore, not surprising, that the leaning revetment has been recommended by many writers,† but I know only one instance of

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top. Thus, not only the revetment, but also the counterforts, are countersloping, the latter, towards the top, in a more than usual proportion, for the steps there are equivalent to a counterslope, whose base is seven eighths of its height. Large masses of freestone were used in the construction of this wall, which was built by tide work.

* It may here be remarked, that, it would be very ill-judged, if, with a view to resist cannon shot more effectually, any engineer, in planning a fortress, were to increase the general thickness of masonry, beyond that due proportion, which is sufficient for resisting the pressure of earth, and insuring the durability of the work. For, in a warmly contested siege, it is not to be expected, that above 100 running yards of revetment should be battered, whereas the outline of the reveted works of a large fortress may be several miles in extent.

† Speckle, a German writer before mentioned, recommended leaning revetments of uniform thickness throughout. There is reason to believe,

its having been used in a profile of respectable height: I allude to the fortified town of Sedan in France,* a bastion of which, on being pulled down in 1805, was found to have been reveted in the following manner:

The walls had a perpendicular height of 32 feet, and parallel slopes of one-fifth of their height, both in front and rear; but instead of being made of uniform thickness, according to the usual custom, every portion of the back of the revetment, between two adjoining counterforts, was laid out in the form of a semicircle, so that these parts were built like concave semicylinders, the least thickness being 5 feet 4 inches, which was equal to one sixth part of the height, and the greatest thickness being 10 feet, 11 inches.

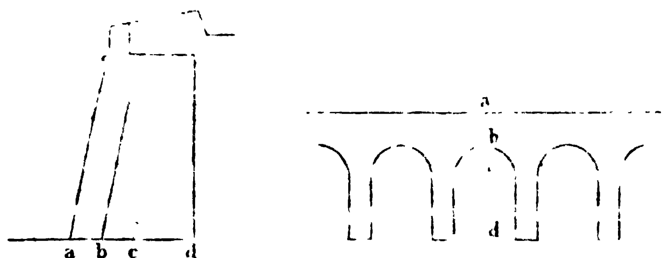
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that Coehorn used leaning revetments, whose exterior slope was rather greater than their overhanging slope, so that they were somewhat thicker at bottom than at top. Charles Bisset, a British engineer, who served with the rank of lieutenant, in the famous defence of Bergen-op-Zoom in 1747, and who appears to have closely studied the works of Coehorn, in his Treatise on Fortification, published a few years afterwards, recommends leaning scarp revetments, 4 feet thick at top, and having an exterior slope of one third, but an overhanging slope of two fifteenths of the height only, so that the masonry gains in thickness towards the bottom, in the proportion of one fifth of the height. His counterscarp revetments he makes only 3 feet thick at top, but similar to the above in other respects; and in both, instead of counterforts he proposes to use horizontal courses of flat stones, projecting about 3 feet from the back of the revetment, thicker some inches in rear than in front, so as to form a dovetail, their least thickness being about 5 inches, and perforated by two or three holes, for picketing them into the mass of supported earth by oak stakes. He proposes that these binding stones, as he calls them, should be engaged about 1 foot in the masonry of the revetment, and that there should be one horizontal course of them in every 8 or 10 feet of height.

If leaning revetments were to be used in military works, it may be remarked, that one of uniform thickness, with common counterforts, and with a smaller exterior slope, would be preferable to the above.

* The works of which are supposed to have been constructed by Pasino, an Italian engineer, who published a book on fortification in 1579.

Behind these semicircular portions were counterforts, 3 feet $2\frac{1}{2}$ inches wide, and placed at central intervals of 14 feet 5 inches apart: they were vertical in rear, being 4 feet long at top, and 10 feet 5 inches long at bottom; so that their mean length was equal to 7 feet $2\frac{1}{2}$ inches; and consequently, on taking a continued section right through the revetment and one of the counterforts, the mean thickness or depth of masonry, measured from front to rear, was 18 feet $1\frac{1}{2}$ inch, which was in the proportion of rather more than $\frac{9}{18}$ths of the height.* The annexed figures, in which the corresponding parts are distinguished by the same letters, represent a section, and a foundation plan, of the revetment, which has just been described.



But although the above singular profile is the only right-lined leaning revetment of any magnitude, of which I can find an account,† profiles of this description, on a small scale, have been

* I have taken the above dimensions from Colonel Maynicl's work, but correcting, by help of one of his plates, an error, which appears to have crept into his text, regarding the length of the counterforts.

† It is true, that, towards the right of Chatham lines, both the scarp and counterscarp are faced with leaning brick revetments, about 3 feet thick, and having slopes of rather more than one third, without counterforts. But although the height of the scarp revetment, alluded to, is not less than 34 feet, it is to be observed, that, on both sides of the ditch, the walls are built against chalk rock, which has no tendency to fall; and, therefore, this example does not afford any rule for revetments, intended to support common earth; particularly, as in all those parts where the chalk proved unsound, a greater thickness of masonry was added.

in constant use. For example, in Fort Cumberland, near Portsmouth, all the interior slopes of the parapets, as also the cheeks of the embrasures, and the extremities of the various portions of the banquette, are reveted by leaning brick walls 14 inches thick, with slopes of $\frac{1}{8}$th.* The interior slopes of the parapets of the covered way, and of the traverses, in permanent works, are also frequently reveted in a similar manner.

The use of brickwork for the smaller revetments of fortified places, such as have been described, is very common, and as far as economy is concerned, it is certainly preferable to sodwork, which has also frequently been used for the same purpose; as the latter is exceedingly troublesome in execution, and requires continual repairs. Having introduced this subject, I shall remark, that of many forms which have been proposed, rectangular sods, about 8 inches wide, and 16 inches long, to be built headers and stretchers, like common bricks, are the best: and that sod revetments, when such are used, ought not to have a less slope than one third of the height; for if built steeper than the above proportion, the work will soon decay, even if the revetment were capable of standing, which is not likely.†

* The parapets of this work, which are formed of earth, have also an exterior brick revetment, 4 feet high, 2 feet 9 inches thick at top, and 3 feet thick at bottom.

In the interior revetments of the parapet, described in the text, the foundation is about 1 foot deeper than the base of the banquette, the total height of brickwork being 8 feet 6 inches; so that in those parts, where there are no embrasures, nearly one half of it is buried. The foundation is 1 foot 8 inches thick: the thickness of the remainder of the wall being reduced by offsets to 14 inches, at the height of about 1 foot 3 inches from the bottom.

† These remarks are made from experience, having myself, unsuccessfully, tried steeper slopes, and other forms, such as triangular sods, trapezoids,

As small brick revetments, although much more durable than sodwork, are not convenient, when works are actually attacked, a better mode than either, in large fortresses, at least in those parts where there are no embrasures, will be to form the interior slopes of the parapets with a base equal to the height, by which means they will be able to preserve their form permanently, although unreveted. In this case, the perpendicular height of the parapet must be 3 feet 10 inches, or 4 feet only, and the width of the banquette not more than 2 feet. And the same profile may be adopted for the salient places of arms, and branches, if not for the whole of the covered way.* The section of the parapet of a

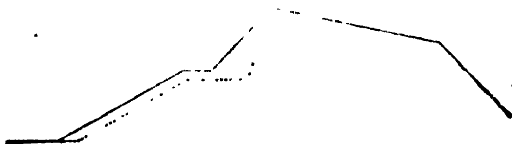
&c. which have often been recommended with an idea of economizing that material.

In building with sods, the grass is laid undermost, and wooden pins are generally used to bind the work together. Each course is usually about 2½ inches high, so that 24 sods will build 10 running feet in length, and 1 foot in height, of sodwork; by which proportion, the number of sods necessary for reveting any part of a work may easily be calculated. If the grass is good, 100 superficial feet of ground ought to furnish 112½ sods of the dimensions stated in the text, but in this last calculation, I have made no allowance for waste, so that 1 sod per superficial foot of ground, would probably be a proper estimate. Sods cannot be cut by the common spade, without great waste both of time and materials. Two sod spades, both of a pointed form, are necessary for this purpose, a small one to be worked vertically by the foot; and a large one to be pushed horizontally forwards, by the hands and thighs.

To build sod revetments, properly, is one of the most tedious operations, in which men can be employed. Stone or brick walls may be constructed with much greater celerity, and with much less expense of workmanship. Indeed I have found by experience, that three or four batteries for heavy guns, might be commenced and finished with fascines or sand-bags, in a much smaller space of time, than proved necessary, merely for reveting with sods one single battery of the same description, after all the laborious parts of the work had previously been completed.

* This arrangement, to which I do not see any serious objection, particularly if the covered way is palisaded, would, if adopted, lead to the use of lock traverses, in lieu of the present more common form.

curtain, or other work of a fortress, so regulated, is exemplified by the annexed sketch, in which the dotted lines show the steeper interior slope, and broader banquette more commonly used.

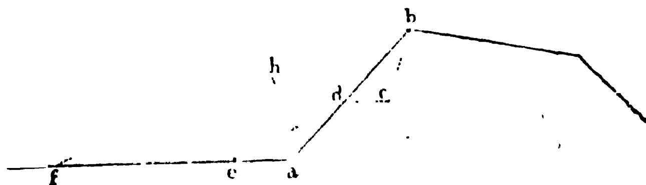


It will be evident, by inspecting this figure, that the profile, now suggested, which is much cheaper than any other mode of construction, will be sufficiently convenient for the use of musquetry;* for if an enemy attempted a sudden assault, the ban-

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* The same profile will be equally suitable for the parapets of field works, intended to be defended by musquetry, if materials for reveting them are not to be had, or scarce.

With a similar view of economy, some French authors have recommended, for the interior of the parapet of a fortified place, a very different profile, from what I have suggested in the text; for they propose to lay out the above part of the work, without any banquette, in one continued slope, whose base shall be a little greater than the height, as represented by the line, a b, in the following figure; alleging, that the banquette may



soon be formed, in case the fortress should be attacked, by scarping away the upper part, d c b, of the above slope, and applying the materials, thence obtained, to the bottom of the same, in the form, e a d. (*See Bousmard's Essai Général de Fortification, and St. Paul's Traité Complet,* &c.)

A very little reflection may serve to convince the reader of the glaring defects of the system, now under consideration; for, if a place, whose parapets were so constructed, were suddenly attacked by assault, it is evident, that it would be quite impossible for the garrison to annoy the enemy by a fire of musquetry, unless they climbed upon the top of their

quettes are in such a serviceable state, as will enable the defender's troops to act to advantage: if, on the contrary, he should lay regular siege to the place, which is a work of time, the profile of

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own parapets, and formed there; in which case they would themselves be more exposed than the firing parties of the assailants.

An idea has been suggested by Capt. W. Reid, of the Royal Engineers, that in certain peculiar cases, the interior of a parapet may be formed without any banquette, not in the mode, which has just been commented upon, in which the slope is too steep for the movements of troops, but at uch greater slope, such as f b, having a base of about three times its ht, so as to be practicable for men throughout its whole extent. If this plan were carried into effect, it will be evident, that a soldier, after advancing to a certain height up the slope, will come to some point, h, where he will be able to fire over the parapet, and yet derive considerable cover from it, against an external enemy; and in an assault, a body of the besieged may move forward in good order, and charge the head of an escalading party.

Captain Reid particularly recommends this profile for the salient places of arms, and the adjoining branches of the covered way of a regular fortress, which parts of the covered way, he conceives, ought not to be constantly occupied and manned, as a defensive post for troops during the course of a siege; and, consequently, that they should neither be palisaded nor traversed, according to the common system. If so constructed, the above-mentioned portions of the covered way would serve for assembling the troops, destined for a sortie, who might march out from thence in large bodies, both of cavalry and infantry, regularly formed for the attack, instead of debouching by small sections from the common sally ports: and, after the affair was over, they would also have a greater facility of retiring in good order, supported by reserves, posted in the re-entering places of arms, which are the only parts of the covered way supposed to be palisaded and retrenched. In a covered way, constructed according to Capt. Reid's system, if we suppose the height of the crest of the glacis above the general level to be 7 feet 6 inches, and the total width, measuring from that point to the brink of the counterscarp, to be 31 feet 6 inches, the base of the reverse slope of the glacis ought to be about 22 feet 6 inches, which is in the proportion of three times the height; for experience has shown, that men cannot conveniently act on a much steeper slope, if the height exceeds 3 feet. Hence there would remain, towards the rear of the covered way, a level space of 9 feet only; but as the

any part of the fronts attacked may very easily be altered, if it should be judged necessary, to the more common form represented by the dotted lines.

CHAP. XXVII.

THE SAME SUBJECT CONTINUED.—OF THE MODES OF SECURING UNFAVOURABLE FOUNDATIONS, BY MEANS OF PILES, &c.—COFFERDAMS AND CAISSONS EXPLAINED.—REMARKS ON THE THEORY OF ARCHES.

Having, in the three preceding Chapters, fully discussed the general principles, according to which the form and dimensions of revetments ought to be regulated; it now only remains to explain the mode of securing their foundations in unfavourable soil. In treating this part of my subject, I shall not enter very minutely into details, as the consideration of these belongs rather to Practical than to Elementary Fortification.

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slope in front of it would also be perfectly practicable for every movement of troops, the narrowness of this space is not an objection.

As applied to the advanced portions of a covered way, the suggestion, which has just been stated, appears worthy of attention. With respect to the parapets of defensive works, we found, on trial, that there is a very serious disadvantage, in so great an interior slope; namely, that the common means of securing men, posted in rear of a parapet, by sand-bags, crennel baskets, &c. forming loopholes for them to fire through, whilst they rest their pieces on the superior slope, cannot be used to advantage, in this new profile, unless the defenders were either to kneel in an inconvenient attitude, or to lie down, which would be still more aukward. If, in any case, it should be judged essential to have a practicable ascent to the top of a parapet, I should therefore recommend, in preference, dividing the height of the interior slope, as measured above the level of a common banquette, into three equal parts, and at each of the two intermediate points of division, to form a step of 1 foot in width. The rear of each step should be reveted with a couple of courses of fascines, so as to stand nearly perpendicularly: otherwise, even this method would remove the banquette too far from the interior crest of the parapet.

The unfavourable soil, alluded to, is that, which is of a soft nature, so that, when loaded with any massy body, such as a revetment or substantial building, unless due precautions, which shall be described, are previously taken, it must necessarily give way under the weight; and as such soil is seldom of an uniform nature, it will yield in some places more than in others, so that the walls, being unequally supported, will crack in various parts, and certain portions, being separated from the remainder of the masonry, will slide forwards or fall; or if neither of these effects takes place, still the work will remain in a ruinous and unserviceable state.

The best expedient for securing foundations, in such soil as has been described, is to drive down strong pointed piles of timber, hooped at top, and shod at bottom with iron, at regular central intervals of from 3 to 4 feet apart, within the whole extent of the space, that is proposed to be built upon. After these piles will go no deeper, whether from meeting a stratum of more tenacious soil, or otherwise, * their heads are sawed off at any height judged most convenient, and are connected by transverse beams or sleepers, of proper strength, of which there is sometimes a double row, forming a kind of grating: over these are laid strong planks, seldom less than 4 inches thick; and upon this planking or wooden platform, is built the foundation of the required wall or revetment. The piles may either

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* Before the foundation of any great work is commenced, the nature of the soil beneath must always be examined with great care, which is done by probing with an earth borer, or large augre, made for the purpose, having its shank composed of a great number of joints of moderate length, screwing into each other, by means of which the operation may be continued to any depth judged necessary. This instrument, being occasionally pulled out of the ground, by a gin and tackle, or other convenient machine, always brings up, in the hollow part of the augre, a specimen of the lowest stratum of soil pierced by it. The persons employed, in thus sounding for a foundation, ought not to stop, on finding a hard stratum, such as gravel, &c. but should ascertain by boring deeper, whether the thickness of it is sufficient to insure the safety of the proposed work.

be driven into the ground vertically, or with a certain degree of obliquity. The operation is performed by means of an engine named a PILE DRIVER, in which a great weight, called THE MONKEY, or sometimes the ram, is raised to a considerable height, and then suddenly dropped upon the head of the pile, which process is repeated, as long as it continues to produce any effect. Thus the foundations of revetments, or other walls, so secured, are in reality supported by the piles, not by the surface of the mud or soft soil, with which the planking beneath them is in immediate contact. And as the force of percussion, by which the piles are originally driven, is much greater than the mere pressure of dead weight, it follows, that if the piles are of proper strength, after each of them shall have been driven as far as it will go by the former force, by means of a pile-engine of sufficient power, there is no possible weight of masonry, which can afterwards be brought to press upon them, that will be capable of sinking them deeper.* Hence a revetment may derive as much security in soft soil, from a properly piled foundation, as if it had been built upon solid rock.

When piles are used in foundations, the total number necessary, together with their thickness or strength, ought, of course, to bear a certain proportion to the weight of masonry, eventually to be

* Mr. Perronet, a civil Engineer, who executed some of the finest bridges in France, in his " Description des Projèts et de la Construction des Ponts," &c. asserts, that the shock of a monkey of 600 lbs. weight falling 4 French feet, is equal to the pressure of a weight of 773,000 lbs. French: but he grounds this opinion solely, upon an experiment, tried by another Frenchman, who is said to have ascertained, that a body weighing only $2\frac{1}{2}$ lbs., if dropped through a height of 7 inches, will produce an effect equal to that of a dead weight of 400 lbs. I conceive, that it would be desirable and useful to have some experiments for investigating this subject, tried on a larger scale; for in the above, both the weight of the body dropped, and the height of its fall, appear to me too insignificant to afford satisfactory grounds for calculating the effect of such great weights, as are commonly used in pile driving.

supported by each, which may easily be calculated.* The strength, proper for each pile, must also, in some degree, depend upon the nature of the soil, for it must be evident, that when that has not

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* For example, if the scarp revetments of the inclosure of a fortified place are founded upon piles, placed at intervals of 3 feet apart, there will be one pile to every superficial yard of foundation; and consequently, if the height is supposed to be 30 feet or 10 yards, each pile will have to support 10 cubic yards of masonry; to some of which may be added about 3 cubic yards of earth, if the profile is partially reveted, without a berm. Now, if we suppose the revetment to be built of stone, weighing 160 lbs. per cubic foot; and that the earth above it weighs 100 lbs. per cubic foot; the weight pressing upon one pile will be 43,200 lbs. of masonry, and 8,100 lbs. of earth: total, 51,300 lbs.

In the foundation of bridges, the piles under each pier are more loaded than those of a common revetment, for they have not only to support the weight of masonry, resting vertically over them, but also that of one complete arch. For example, in the bridge of Neuilly, near Paris, constructed by Mr. Perronet, the arches of which are 128 feet span (English measure) the weight of masonry resting upon the foundation of each pier is equal to about 15,417,648 English pounds, which being supported by 135 piles, the weight pressing upon each pile is consequently equal to about 114,201 lbs. These piles were of oak, and about 12¾ inches mean diameter, and cut off to the average length of about 13 feet, after being driven home.

Mr. Perronet is of opinion, that round oak piles, such as have generally been used in France, if of 8 or 9 inches mean diameter only, should not be loaded with more than 50,000 lbs.; but that piles of 12 inches mean diameter may be loaded with 100,000 lbs. each, and that generally speaking the weight to be supported should be in proportion to the square of the diameter of the pile nearly.

It will be obvious, that the monkies used for driving foundation piles, if dropped from an equal height, should be in direct proportion to the weight of masonry eventually to be supported. Monkies of various weights, from 1000 to 2000 lbs. have commonly been used for this purpose. Those generally employed at the bridge of Neuilly were of different weights, from about 1160 to 1530 English lbs.; and were worked by parties of from 36 to 47 men, pulling together, by means of small ropes attached to a great or principal rope, who did not raise their respective monkies more than about 4 feet 6 inches at the utmost, previously to each blow. Hence on a reference to the other particulars, before stated, the execution of the

sufficient consistency to prevent the upper part of the piles which are driven into it, from bending or moving laterally, when acted upon by a certain force, they might, if their thickness was inconsiderable, be liable to be bent or broken, somewhere towards the top, by the superincumbent mass of masonry, notwithstanding that they might remain perfectly well secured at bottom.* Hence the piles

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bridge of Neuilly may be considered as a practical experiment, on a great scale, proving that the shock of a body of about 1200 lbs. falling through a space of very little more than 4 feet, is superior to the action of a dead weight of rather more than 114,000 lbs.

In driving piles of from 48 to 53 feet long, and from 21 to 25½ inches thick at the top, such as formed a part of the piers of a large wooden bridge at Saumur, we are informed by the same author, that it was judged necessary to use monkies weighing about 4320 English pounds. This was owing chiefly to the extraordinary thickness of the piles.

Pile engines worked by a great number of men, by force of hand alone, are called, by workmen, RINGING PILE ENGINES, to distinguish them from the common pile engine more generally used in this country, in which the monkey is raised to the height of from 25 to 30 feet, by the labour of four men, aided by machinery. In the former kind of pile driver, which has almost always been used in France, I am not aware that the monkey has ever been raised more than about 4 feet or 4½ feet at the utmost, according to the system before mentioned, which practice must of course be very prejudicial to the effect of the engine; and a perseverance in it can therefore only be ascribed to the power of old habits; for it must be evident, that by a different arrangement of men hauling, the weight might be raised by them to any given height, whether aided by a mechanical power or not.

The apparatus for working the pile engines, commonly used in England, is very compact and simple. It consists of an iron wheel and axis of moderate size, worked by a small iron pinion, to which, motion is communicated by a couple of winches. The fall, or lower end of the chain, by which the monkey is raised, is attached to and winds round the axis of the wheel.

* One of the piers of a bridge at Tours, supported by 65 oak piles, 8 feet long, and about 9¼ inches mean diameter, suddenly gave way in 1777. The weight of masonry pressing upon each pile, at the period of the accident, is calculated, by Mr. Perronet, to have been equal to about 166,212 English lbs.; which, according to his opinion, stated in the preceding note, was more than double of what ought to have been applied to piles of that scantling. They were firmly fixed at bottom, in very

used for supporting a revetment, in very soft soil, ought to be thicker than others of equal length, intended to support a similar revetment founded upon soil, whose upper surface has a greater degree of tenacity.

As a further precaution for securing piled foundations, it is also usual to clear out about 18 inches of the mud or soft soil, and to fill up the vacant spaces, thus formed between the heads of the several piles, with rough brickwork or rubble masonry, which is carried up to the same height as the top of the sleepers or grating, so as to correspond with the level proposed for the bottom of the planking.

But to enlarge upon the proper dimensions and use of foundation piles would lead us too far into detail. I shall therefore only remark, that in revetments, such as are applicable to military purposes, it can never be necessary to use piles more than 1 foot in mean thickness, or to place them nearer to each other than at central intervals of 3 feet; for experience has proved, that piles, so regulated, if driven by engines of sufficient power, are capable of securing the foundations of much greater masses of masonry, than are ever used in works of fortification.

It is moreover to be remarked, that there have been many instances of revetments sliding forwards, in consequence of the pressure of earth in rear of them, when built upon very bad foundations.*

tenacious soil, but the remaining parts of them, towards the top, derived little or no aid from the surrounding soil, which was of a soft quality.

It is obvious that piles in this predicament, supported at bottom only, may be compared to wooden pillars, in architecture, the thickness of which must always be increased in proportion to their height, although there may be no difference in the actual weight to be supported.

* The scarp revetment of the face of a ravelin slided into the middle of the ditch at Bergues St. Vinox, in Flanders, about the beginning of the last century: part of the old wharf at Woolwich slided forwards into the Thames about the year 1750: and at Juliers, a counterscarp revetment, said to have been constructed from time immemorial, suddenly slided upon

It is therefore not sufficient towards the stability of a profile, that the piles have strength enough to sustain the whole weight of the masonry, and prevent it from sinking; unless further precautions are also taken, to render it impossible for it to slide forwards upon the platform, which serves as its base.

In order to effect this object, a continued line of exterior piles, nearly touching each other, is sometimes driven, immediately in front of the revetment, the heads of which, by projecting a little higher than the bottom of the masonry, will of course effectually prevent it from moving. Sometimes strong timbers, laid longitudinally all along the foot of the wall, are used for the same purpose, which must be firmly connected with the exterior piles or grating; but in this case it is not necessary, that the exterior piles should be driven near to each other, as in the former method: consequently the present is the most economical expedient of the two. Instead of commencing the work horizontally, according to the practice which is common and proper, in walls not intended to retain earth, &c., the foundations of revetments, particularly in bad soil, should always be laid out according to an inclined plane, which must necessarily assist greatly in counteracting the above tendency; and when this arrangement is adopted, a part of the supporting piles, particularly those towards the front, should be driven obliquely, in a direction perpendicular to the said plane, or nearly so. These obvious principles have, of late, been generally acted upon by Practical Engineers.

its foundation, in 1807.—(See Belidor's "Science des Ingenieurs," Muller's "Practical Fortification," and Maymel's "Traité," &c.)

From a similar cause, it has often happened, that even the sides of hills, consisting of considerable tracts of land, and covered with houses, gardens, &c. have slided to a considerable distance, when the natural strata below the surface have been oblique, so as to form inclined planes, falling towards a ravine or valley. Such accidents are most likely to be caused by internal water acting upon an inclined stratum of clay. A memorable accident of this kind happened in France, in 1733, at Pardines, near Issoire, in Auvergne.

It is to be remarked, that a continued line of piles, touching each other, driven along the front of a wall, &c., either contiguous to, or at some small distance from, the foundation of the work, with a view of securing it, as above stated, are called SHEETING piles, in order to distinguish them from common foundation piles, &c, and when this term is used, it always implies half piles, if nothing is specified to the contrary.

As such very bad foundations scarcely ever occur, excepting on the sea shore, or on the banks of rivers, or in marshy situations, where harbours, wharfs, bridges, or fortresses with wet ditches are to be constructed; it has almost always been found necessary, in executing such works, previously to inclose the spot, intended for the foundation, by a dam, and to clear out the water from it; an operation which is often the greatest difficulty to be encountered.

The dams, made for this purpose, are called COFFERDAMS. They are commonly formed by driving down two continued lines of piles, parallel to each other, at a certain interval, to any depth judged convenient, and afterwards filling up the intermediate space with clay. The piles used in cofferdams are either called WHOLE OR HALF PILES, according to their scantling. The former are from 12 to 16 inches square. The latter are rectangular, being of the same width as the former, but only from 6 to 8 inches thick.* In commencing a cofferdam, the general line of the work is determined, by driving strong piles opposite to each other in pairs, at intervals of about 10 feet apart. These serve as guides for regulating the others, which may either be composed of whole piles, or entirely of half piles, according to circumstances, the latter being used in preference, for the sake of economy, whenever the pressure acting upon the cofferdam is inconsiderable; but, whichever kind is used, they must always be driven as close to each other as possible. COFFERDAM PILES are sometimes grooved longitudinally, or PLOWED, as it is styled, on two op-

* When the thickness is less than 6 inches, they are sometimes called pile planks.

posite sides, for receiving a vertical rod, called A TONGUE, which connects every adjoining pair of them together; and any PILING thus connected, is said to be DOVETAILED.*

Each line of cofferdam piles is strengthened near the top, and also towards the bottom, by strong beams or ribbands placed horizontally, and firmly spiked or bolted: and the opposite sides of the cofferdam, which inclose the space intended for building, must be connected and braced together by strong transverse timbers, butting against the said ribbands, to prevent the piles from being forced out of their proper position, by the pressure of the external water;† and when the length of these timbers is considerable, they must either be supported by intermediate uprights, or if that is not convenient, they must be trussed, as it is called, according to the principle, which it has been found necessary to adopt, for strengthening the tie beams of the roofs of large buildings. Iron bolts, penetrating through the mass of clay, &c., of which the body of the cofferdam is formed, are used at certain intervals, for connecting the opposite piles and ribbands, both towards the bottom and at top.

When the depth of water is considerable, it is absolutely necessary, that the body of the cofferdam should have a certain thick-

* This expression is used without any reference to the form of the tongues, which are usually rectangular or nearly so. Sometimes dovetailed piling has been executed by using piles, plowed on one side only, and tongued on the other, which method is, of course, attended with greater waste of timber than the former.

† In forming a cofferdam, after the first or guiding piles of each line are driven at open intervals of about 10 feet, as was before stated, one or two pairs of horizontal ribbands are fixed to them on both sides, opposite to each other, between which, grooves are of course formed; and through these grooves, the intermediate piles are afterwards driven, which arrangement is of great use, by confining them in their proper position during the operation. Such of the above ribbands as would interfere with the clay, or other material forming the body of the cofferdam, may afterwards be removed, the remainder being left, for the purpose stated in the text.

ness, and weight, in order to enable it to resist the pressure of the external fluid, especially if it is, at the same time, exposed to the direct action of tides or currents: and clay, as being a water-tight substance, has generally been adopted for that purpose, as was before stated. But it having been found, that a mass of clay was liable to swell, and to bulge or break the cofferdam piles, within which it was inclosed, this material has in some cases been rejected, and bricks have been chosen in preference. These, by their weight, are well calculated for resisting the action of the excluded water, and being laid in horizontal courses, they have no tendency, like clay, to injure the woodwork by a lateral pressure, and consequently a brick cofferdam may be retained chiefly by half piles, whilst if clay were used, whole piles would be absolutely necessary throughout, for the security of the body of the work.* But as the former material is not water-tight, like the latter, it is necessary, in forming cofferdams with brickwork, to caulk the joints of the inclosing piles.

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* I believe that this expedient was first resorted to, in forming the cofferdam for the pier walls of the new bason, now executing in His Majesty's dockyard at Sheerness, by direction of Mr. Rennie The body of the cofferdam is retained by two parallel lines of piles, chiefly consisting of half piles, of from 6 to 8 inches thick, intermixed, in general, at intervals of 10 feet, with whole piles of double that scantling; the strongest of both kinds, and the greatest proportion of whole piles, being of course used in the deepest water. These inclose a space of 6, or in some parts of 7 feet, in width, which is filled with dry bricks built in regular horizontal courses mixed with fine sand; and in front, the base of the work is increased and strengthened by a mass of clay, from 8 to 12 feet wide, which is retained by a third line of piles, also chiefly consisting of half piles mixed with a similar proportion of whole ones. This part of the work is from 8 to 18 feet lower than the former, with the exception of the whole piles used in it, which are of the same height as those of the body of the cofferdam; and which serve to support temporary scaffolds, for the landing and stowage of materials. The joints of the principal piles are caulked.

The clear width of the space, inclosed for building, as measured from front to rear, is about 47½ feet. The sides of the cofferdam are braced, interiorly, at intervals of about 20 feet, by two very strong transverse tim-

When the depth of water, to be excluded, does not exceed 20 feet, or thereabouts, at high water, and the line of work, to be executed, is not exposed to the direct action of tides or currents,

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bers or tie-beams, each about $45\frac{1}{2}$ feet long, one at the height of 4 feet, the other generally at the height of about 21 feet from the top; both of which are strongly trussed together by frame work, and butt against horizontal ribbands not less than 1 foot square, fixed to the piles; to which ribbands they are also connected by struts on each side. Some of these tie-beams are, for greater strength, formed of several pieces of timber bolted together. In proportion as the masonry rises, the lower tie-beams are removed, and shorter pieces butting against each side of the wall are substituted instead of them. Strong iron bolts, about $10\frac{1}{2}$ or $11\frac{1}{2}$ feet long, passing through the brick work, principal piles and ribbands, brace the body of the cofferdam, both near the top and towards the bottom, at intervals of 10 feet apart.

The top of the exterior pier wall is every where on the same general horizontal level, but the foundation is laid out on different levels, according to the depth of the external water, &c. Consequently, the height of the portion of wall already executed varies from 15 to 32 feet. The piles, used in the body of the cofferdam, are on the same level, at top, with the proposed masonry; and their length varies, in various parts, according to the height of the corresponding portion of the wall; but, in no case, have they been driven to a less depth than 10 feet below the foundation of the masonry, which is almost every-where considerably lower than the original level of the bed of the river. In those parts of the work, where the wall is about 30 feet high, the average length of the principal cofferdam piles is said to be about 50 feet: in other parts their length is even more than the above, particularly near the proposed entrance of the bason, where, in consequence of the greater depth of water, &c. some of the piles driven are said to have been nearly 70 feet long. In those parts, where the depth is considerable, before the excavation for the foundation of the masonry could be formed, it was found necessary to secure both the front and rear of the cofferdam, interiorly, by sheeting piles, driven a few feet from the base of it. All the wood work, that has hitherto been mentioned, is of pine.

The revetment itself, which was alluded to in a former note, shall also be described, it being the only example, to my knowledge, of a concave profile, that has yet been executed. The dimensions, that shall first be stated, are such as would all appear in a transverse section of the work, supposed to be taken in that portion of the wall, where the total height is 32 feet, through the middle or widest part of one of the cavities or

striking against it, either perpendicularly or nearly so, a second and simpler mode of effecting the same object may be adopted, which is as follows.

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cells. The front of the wall is a leaning curve, described by a radius of 82 feet 6 inches, of which the perpendicular height is 30 feet 4 inches nearly. The base of the masonry is laid out in front, according to an inclined plane, in the direction of the radius produced, to the distance of 4 feet 6 inches, within which space it falls about 1 foot 8 inches: after which the remainder of it, extending 20 feet, is laid out horizontally, the total thickness at the base being 25 feet. In rear, the wall is formed with small offsets to the height of at least 6 feet upwards, by which the thickness of the work is gradually reduced to the dimensions that shall be stated. Above these the back of the wall is carried up perpendicularly. The thickness of masonry in front of the middle of each cell is 4 feet 6 inches: the central width of each cell is 8 feet 8 inches at top, but it increases, towards the bottom, in consequence of the leaning curve given to the front part of the revetment. The cells are not continued down so far as the base of the work, but terminate each, in an inverted arch, the rise of which is about 4 feet, the least thickness of masonry below it being 2 feet. The masonry in rear of the cells is perpendicular on both sides, and of the uniform thickness of 1 foot 10 inches, above the level of the before-mentioned offsets: and consequently the total thickness of the work at top, as it appears in our supposed section, is 15 feet.

The details, that shall next be stated, are such as would appear in a plan of the work. The length of the cells, which is supposed to be measured in a direction parallel to the general line of the revetment, is 17 feet 9 inches; and they are divided from each other by partition walls 2 feet 3 inches thick, so that their distance from center to center, is 20 feet. In front and in rear, they are bounded by vertical counterarches, abutting against the said partition walls as piers. The span of the curve, which forms the front counterarch, is 17 feet, and its height 1 foot 6 inches, so that the greatest thickness of masonry in front of the cells is 6 feet; the least thickness, opposite to the centre of each being 4 feet 6 inches, as was before stated. The span of each of the curves, which form the rear vertical counterarches, is also 17 feet, and the height of the same is about 3 feet; the thickness of masonry of these last-mentioned counterarches being generally equal to 1 foot 10 inches, as was before mentioned. Thus the upper part of the work, as it appears in a plan, is bounded in rear by a series of arcs of a circle, so that it is of irregular width; its greatest width at top being 15 feet from front to rear, according to a measurement supposed to be taken over the center of one of the cells, as was before stated, and

This consists in forming the cofferdam, by means of one continued single line of piles only, inclosing the space, that is to be built upon. These piles, not being aided by a mass of clay, bricks, or

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its least width at top being 12 feet, which last measurement is supposed to be taken over one of the partition walls or piers. At bottom, the width of the base of the work varies from 22 to 25 feet.

It is proper to remark, that the inverted arch, below each cell, is not a simple arch, as it would appear in a central transverse section, but a kind of irregular elliptical dome; having a rise of 4 feet and a least thickness of masonry of 2 feet below the crown, as was before stated. The front of the wall is built with large blocks of Aberdeen and Cornish granite, in courses of 18, 15, and 21 inches in height, the joints of which radiate from the same center, wherewith the exterior curve is described. All the exterior horizontal joints are chamfered. The remainder of the masonry, including the vertical counterarches, and piers, and inverted domes, is of brick work. The cells are filled with chalk laid in courses, and grouted, excepting at top, where it is proposed to lay a continued paving of large flagstones, extending over the whole work, for the sake of greater strength, The foundations and front of the wall are entirely cemented with puzzolana, which is the best kind of water-cement known: and a proportion of the same is also mixed with the mortar and grout, used in the remainder of the work.

In other parts of the pier, where the height is less considerable, the thickness of masonry in front of the center of each cell is gradually diminished from 4 feet 6 inches to 3 feet, which last dimension is used in those parts where the height is 15 feet; and there the thickness of the brick vertical counterarches in rear is also reduced to 1 foot 6 inches: but the total width at top is equal to from 12 to 15 feet, as in the former described portion of the work: and all other particulars likewise remain the same, excepting that the width of the cells is of course greater and the base somewhat less in the low, than in the higher portions of the wall; the exterior curve being every where described by the same radius. It is to be observed, that the upper course of granite, which forms a coping in front of the wall, is no where composed of pieces less than 4 feet long, although the general thickness of masonry in front of each cell is in many parts reduced to less than the above dimension, as has just been mentioned. The vertical joints of the coping are connected by joggles of the same material.

From the details, that have been stated, it will appear, that in its thinnest parts, the work described will have a base of from $\frac{11}{8}$ths to rather more than $\frac{4}{5}$ths of its height, and a thickness at top of from $\frac{3}{8}$ths to nearly $\frac{1}{2}$ of its height; so that there can be no doubt of its stability.

The soil, that was to be built upon, being a kind of quicksand under

other heavy material, must all be of the strongest scantling, without any mixture of half piles, at least, when the depth is considerable; and peculiar care must be taken, that the ribbands, and

mud, required particular precautions. The foundations have accordingly been secured by round piles of beech and elm, each about 30 feet long, and seldom less than 1 foot in diameter, and driven at central intervals of 3 feet apart, so that there are generally 9 piles in every running yard of foundation, extending from front to rear. The two most advanced piles of each file, which support the inclined part of the base of the masonry, are driven obliquely, in a direction perpendicular to the inclined plane above them: the remainder are driven vertically. In some parts, where the foundation was peculiarly doubtful, the front piles were driven in one close continued line, and are plowed and tongued for the sake of greater security: so that the number of piles, per running yard of foundation, is there greater than the average before stated. Over the foundation piles are laid sleepers of the same timber, all about 1 foot thick, and not less than 1 foot wide: which are covered by a platform of 5 or 6 inch planks, also of the same kind of wood, supporting the masonry. The intervals between the sleepers, immediately beneath the planking, are filled with rag-stones and sand. The monkies of the pile engines used, weighed about 11 cwt.

As a second example of a cofferdam attended with considerable difficulty, in consequence of the depth and rapidity of the water, in which it is constructed, I shall briefly notice that which has been formed, preparatory to building the second stone pier of the iron bridge, which it is proposed to throw over the river Thames at Southwark. The form of the cofferdam is similar to that, which will be given to the pier itself, being oblong and parallel sided, but having the ends curved outwards, in order to oppose the action of the tides. The principal piles are from 12 to 16 inches square, and are said to be from 45 to 50 feet in length, and are driven all round in two parallel lines, without any mixture of half piles, so as to inclose a space of 5 feet, which being filled with clay, forms the body of the cofferdam. These piles stand about 3 feet above highwater mark, the strongest of them being placed in the outer line.

The base of the cofferdam is widened and strengthened exteriorly, by a third line of piling, consisting chiefly of half piles about 7 inches thick, which are about 10 or 11 feet lower at top than the others, so that they are covered every tide. The space between these and the line of piling, before described, is also filled with clay, and varies in width from about 6 to 10 feet, it being widest at the ends of the cofferdam. Intermixed with these half piles, are a proportion of whole piles of greater length, placed at intervals of about 9 feet apart, which serve to prevent barges from in

transverse beams, shall be of proper strength, and well secured. In this kind of cofferdam, tongues and grooves, which are generally dispensed with in the former, are essentially necessary; and the caulking of every joint must be executed with more than usual care.*

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juring the work, at high water. Extra piles have also been added externally, in some parts, for the sake of greater strength. All the piles, that have been described, are said to be driven to the depth of 15 feet below the natural bed of the river. This cofferdam is also strengthened by tie-beams, ribbands, iron bolts, &c., on the same principle as the former one. The interior width of the space inclosed by the cofferdam is about 48 feet.

The whole of the woodwork, hitherto described, is of pine. Round beech piles, 20 feet long, and about 1 foot mean diameter, sleepers of the same wood 1 foot thick, and from 14 to 18 inches wide, and 5 inch planks, also of beech, were prepared for supporting the masonry of the stone pier, the first course of which, I was informed, was to be laid about 8 feet below the natural bed of the river; and which was further secured by a continued line of sheeting piles of pine timber, each about 20 feet long, driven all round within the great cofferdam, so as immediately to inclose the space, that was to be built upon. These sheeting piles were driven by ringing-pile engines worked by about 15 men, the monkies of which weighed 4½ or 5 cwt. All the other piles, that have been mentioned, were driven by common pile engines, worked by 4 men each, the monkies of which weighed about 13 cwt.

The above examples will serve as specimens of cofferdams on a great scale; but I do not vouch for the strict accuracy of all the detailed dimensions, as I have no plans or sections in my possession, but took them partly from observation, without actual measurement, partly from inquiries put to the workmen, who are not always correct in their information, as to the details of works, in which they are employed. What I have stated will, however, be sufficiently correct, to give a good general notion of the manner, in which such works have been executed in this country.

* This method was adopted in building the West and East India Docks, and the wharf wall of the Royal Ordnance Arsenal at Woolwich, which shall afterwards be described (*See page* 686).

In executing the latter work, a rectangular cofferdam, inclosing a space about 100 feet in length, and 19 feet in width, was first formed; and whilst the line of masonry to be built within the above space was in progress, a second cofferdam of the same length was formed in continuation.

Whatever species of cofferdam may be adopted, pumps mu be use for clearing out the water from the inclosed space, whic in England, are always worked by steam engines;* but countries, in which fuel is expensive, other machines are often us for the same purpose, which it would be superfluous to mention.

When it is absolutely necessary, that water should be exclude

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After the first portion of the masonry was built, the finished extremity of it was connected to the front and rear of the cofferdam, by piles driven across the intermediate spaces, with the same precautions as the others, which being done, the original transverse line of piling that divided the first from the second cofferdam was removed. And thus, in every cofferdam, excepting the first, the finished portion of the wall itself, eventually became a part of the inclosure, by which the water was excluded. The same principle must be followed in executing all continued lines of wharf revetment, by means of cofferdams. In the pier wall at Sheerness, some of the portions of the cofferdam were 270 feet long.

* In building a long line of wharf, it is always necessary to have the pumps near the extremity of the work, for which reason they must be moved from time to time, so that they may sometimes stand more than a hundred yards distant from the engine, by which they are to be worked. The most convenient mode of communicating the power is by an endless chain passing round a couple of wheels or cylinders, one of which is attached to and moved by the steam engine, whilst the other works the pumps. The upper and lower portions of the chain are each supported in a position nearly horizontal, by being made to pass over large pullies, fixed to frame work erected for the purpose, at intervals not exceeding 30 feet. In proportion as the pumps are moved, the chain is lengthened. This method has been used in executing the pier-wall at Sheerness before described, in which the pumps are worked by a steam engine equal to a 14-horse power. The engine used for the same purpose in building the new wharf-wall at Woolwich was equal to a 6-horse power. In building the first, and in commencing the second pier of the proposed iron bridge at Southwark, a 14-horse-power steam engine was used, which proving insufficient for clearing the foundations of the latter pier, a 16-horse-power engine was ordered in addition; but on trial, one half of the said additional power was found to answer. It will be obvious, that great varieties in the power necessary must often be expected to occur, in draining the foundations of extensive works.

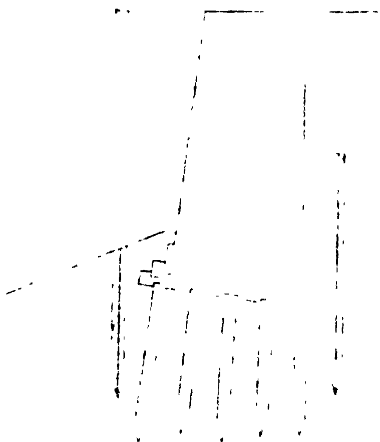
and at the same time the soil to be built upon proves, on due examination, of so favourable a nature as not to require piling, the foundation of any mass of masonry of inconsiderable extent may be executed by means of A CAISSON, which is a strong water-tight, flat-bottomed, wooden vessel, open at top, and a little larger each way, than the base of the proposed masonry, the dimensions of which will consequently determine its form. When this mode is decided upon, the spot, chosen for the foundation, is previously levelled, and cleared of superfluous soil, by the dredging machines usually employed for that purpose, in rivers and harbours; which being done, the caisson is towed into its place, and sunk, by letting in the water: and if it appears to be well placed, the water is pumped out, and the masonry commenced by building upon the bottom of the wood-work, the sides and ends of which, being originally prepared with that view, are eventually removed, when the work is raised to a sufficient height. This method, which was used in founding the piers of Westminster and Blackfriars Bridges, is not suitable for military revetments, or other long continued lines of masonry.*

* The foundations of the piers of Westminster and Blackfriars Bridges, as also that of the new iron bridge, near Vauxhall, were all executed by means of caissons of a rectangular form; but although each of these works succeeded, it may be remarked, that the difficulties of the execution would probably have been much diminished, if the ends of the caissons used had been differently constructed, so as to oppose angles or curves, instead of right lined perpendicular surfaces, to the action of the tides. As for rectangular caissons or cofferdams, for the piers of bridges, I conceive that they ought always to be rejected, excepting in still water.

In building the foundations of works, in tide rivers and harbours, the cofferdams or caissons used, are not always raised to such a height, as entirely to exclude the water at all periods of the tide: but are sometimes only made a few feet higher than the common low water mark. In this case, the water is pumped out about the time of low water, to such a depth as to allow the masons to work, who continue as long as the tide will permit them. Masonry, thus executed, is said to be built by tide-work.

Of late, the diving bell has also been used to advantage in this country, for preparing the foundations of walls to be built under water, when it has either been judged inconvenient or impracticable to form cofferdams.*

The whole of the foundations of the revetments of the fortifications of Portsmouth and Portsea were secured by means of piles and the same expedient was used in the new wharf wall of the Royal Ordnance Arsenal at Woolwich. This last named work, of which the annexed figure represents the general section, having no counterforts, has been built considerably thicker, in proportion to its height, than the generality of works of the same description. In this profile the exterior slope is in the proportion of $\frac{1}{8}$th; the wall,



* In another Government wharf, now about to be built at Sheerness, by direction of Mr. Rennie, which, when finished, is to be given over to the Ordnance Department for a Gunwharf, no cofferdams are to be used, but the foundation piles, when driven, are to be cut off, and the sleepers and platform are to be fixed by workmen descending in diving bells; the bottom being previously cleared and levelled, if necessary, by the same means. The stones prepared for the foundation are about 10 or 11 feet long. By means of a simple piece of machinery, they may be lowered into the water with great nicety, nearly over the precise spot, where each is to lie, after which the workmen will descend and rectify their position, if necessary, and apply the cement, &c. This ingenious expedient has, I am informed, been already used with success by the same civil Engineer, under similar circumstances, in extending Ramsgate pier. I am not aware, that the diving bell was ever before applied to any purpose of much practical utility.

which is perpendicular in rear, is 22 feet in total height, foundation included; and 9 feet thick at the top, and 12 feet thick at the bottom, at the height of 2 feet above which, there is an offset of 3 inches; so that the mean thickness of masonry is very nearly equal to one half of the total height. There are five lines of foundation piles in the width of the section, corresponding with the thickness of the wall, as shown in the figure; of which the exterior pile is driven obliquely, so as to agree with the slope of the exterior surface of the masonry nearly, whilst the rear one is driven vertically. All the foundation piles are 12 inches square, and their average length or depth is from 14 to 16 feet. Each file of them, as it may be termed, is connected at top by a sleeper 12 inches square, notched on its lower side to the depth of 1 inch for receiving the heads of the piles. These sleepers support a platform of 4-inch planks, that forms the base of the masonry, as also a hurter or longitudinal beam 12 inches square, placed in front of it, to prevent the sliding motion before mentioned. This is further counteracted, by the form given to the foundation, which has been laid out according to an inclined plane falling towards the rear, and nearly perpendicular to the exterior slope of the wall. The two detached piles, in front and rear, represent the two lines of cofferdam piles, that were used to exclude the water, &c., from the excavation, whilst the foundation was forming: those in front were originally from 32 to 36 feet long, and at top stood equal to the revetment itself in height, but were afterwards cut off level with the common bed of the river Thames; whilst those in rear, which were of the same scantling, and from 24 to 26 feet long, were left standing, to a much greater height than the former, as represented in the figure. The cofferdam and foundation piles were of pine; the remainder of the wood-work, that has been described, being of oak. Trenails of the last-mentioned wood were used to connect the various timbers of the foundation

together. The masonry is of Dundee stone, backed with brick-work.*

* The dimensions of the wharf walls, built by direction of Mr. Telford, in the harbours of Aberdeen and Dundee, are as follows. The profile is of the common sloping form, its exterior slope being in the proportion of ⅛th nearly. The average height was 16 feet: the thickness of masonry at top, below the coping, 4 feet: the thickness at bottom 6 feet, with an offset at about ⅓d of the height, measuring upwards. The masonry consisted of large stones, backed with thin stone rubble: the counterforts, which were also of stone rubble, were 3 feet square, 1 foot lower than the back of the revetment, and placed at central intervals of 15 feet. They were each connected to the revetment by timber ties, in two places, at different heights. In some parts the height of the profile increased to 22 feet, and there the thickness was of course augmented in proportion. Beneath the lowest exterior course of the revetment, was laid a longitudinal course of 4-inch planks, resting on piles placed at certain intervals, besides which dovetailed sheeting piles were driven, in several parts, along the front of the base of the masonry, above which they projected a little, in order to prevent it from sliding, or from being undermined by the action of the water, or otherwise.

These wharfs were executed by tide-work, whereas most of the former works of the same description, that have been noticed, in this or in the preceding chapter, either have been, or are to be executed by cofferdams, totally excluding the water. It is to be remarked, that the system above described, of securing the foundation by one line of piles only, immediately beneath the front of the base of the masonry, has also been adopted in other works of a similar nature, in which the ground, although somewhat soft, was rather of a favourable nature than otherwise.

In all wharf walls, it is necessary to protect the front of the masonry by strong pieces of timber, capable of fending off ships or barges, from whence they are called FENDER PILES, being almost always placed vertically. Those used in the new wharf at Woolwich are 12 inches square, and placed 12 feet apart, and are secured at bottom by stone corbels, projecting from the body of the wall, to which they are fixed at top, by metal bolts or cramps; and this is the system most commonly followed. In the West-India Docks, a different arrangement has, however, been adopted, as a couple of courses of FENDER BEAMS have, for the same purpose, been fixed horizontally, along the whole front of the wall, at the distance of 4 feet apart, the uppermost of which is placed about 6 feet lower than the top of the masonry.

It may easily be conceived, that between soft mud, which requires a foundation of piles, planking, &c., such as has been described, and rock or very tenacious earth, in which no wood-work, whatever, is necessary; there may be many intermediate qualities of soil. And in some of these, piles may be dispensed with, as it will be a sufficient precaution to lay a platform, consisting of a double flooring of planks, crossing each other at right angles, under the whole of the foundation of the masonry; which planks may, in certain cases, be placed at intervals, so as to form a grating.

This expedient is not, however, by any means applicable to revetments, or retaining walls, when the soil to be built upon, is at all doubtful: because in these, independent of the actual weight of the masonry, which must always cause it to sink more or less, there is also a pressure of earth in rear, which, for a reason stated in a former chapter, is often liable to vary, sometimes producing little or no effect upon the wall, at other times tending to overset it with great violence, and that not generally, but partially.

But it is to be observed, that in soil, in which it would not be safe to build revetments, properly so styled, without piles, the simple grating or platform may often suffice for securing the foundation of any substantial building or mass of masonry of limited extent, which is not like a retaining wall, exposed to a partial or variable lateral pressure, on one side only. When this expedient is adopted, in the construction of a tower, the base of the work should have a continued foundation of solid masonry, throughout, connected to the exterior walls, by inverted arches. This arrangement, which has actually been adopted in most of the Martello towers, built in this country, by binding the whole mass into one body, will take away all tendency to crack, which might otherwise arise, either from some difference of consistency, in various portions of the supporting soil, or from some inequality of pressure on the part of the masonry: and by increasing the base, it will, at the same time, greatly diminish the sinkage, for which reason, the grating

should not merely be continued entirely under the whole foundation of the tower, but should project some feet beyond it on every side. It is likewise essential, that the center of gravity of the whole mass should correspond with the center of the tower, as nearly as possible, making the exterior walls of uniform thickness all round; in which case the tower, if it does sink, as must always happen more or less in soft soil, unless piles are used, may be expected to sink more equally, than if this precaution were neglected. For if the walls are built thicker on one side than on another, the former, as being the heaviest, will sink the deepest, so that the tower will lose its original level. To decide in what peculiar cases a simple grating or platform without piles may be adopted with safety, must of course be left to the judgement and experience of the Engineer employed: I shall however conclude by again remarking, that to revetments, in general, it is entirely inapplicable: and even for towers and other masses of masonry, not used as retaining walls, it is of a precarious nature, and not to be trusted to without great caution: for, in building upon very soft soil, I have known several instances of this expedient having been tried, none of it having succeeded.*

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* The towers, built on the coast of England, were founded on a great variety of different soils, some of which were very unfavourable, and in these, wooden gratings were always used; which consisted of a double course of elm planks, crossing each other at right angles, each of the planks being about 14 or 15 inches wide, and 6 inches thick. The mud was usually cleared out to a depth of two or three feet below the level of the proposed grating, and the excavation filled with shingle, upon which the first set of planks were laid, parallel to each other, at clear intervals of about one foot. These intervals being filled with dry bricks and grouted, the second course of planks was next laid transversely over the former, and connected to it by oak trenails: and the new intervals thus formed were also bricked and grouted as before. Thus was formed a base, partly of bricks and partly of wood, upon which the foundation was begun with Swanwich stones; the remainder of the work being afterwards completed with bricks.

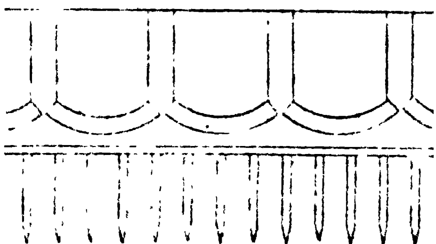
This expedient in all cases completely prevented the masonry from

I shall here remark, that in unfavourable soil, a continued foundation of solid masonry is also suitable for those spaces, which are comprehended between the counterforts of simple revetments, or between the piers of counterarched ones.*

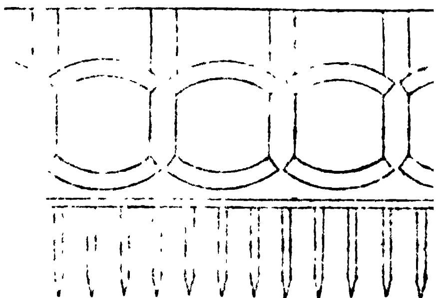
cracking or separating, but in other respects it failed in very bad soil; for I am informed, that two or three of our towers, have not only sunk considerably, but have lost their proper level, by sinking unequally, so that their slopes are quite different from what was originally intended. To build the walls of a tower of uniform thickness, as was before recommended, may lessen this tendency, but cannot do it away entirely, because even the weight of the heavy guns mounted afterwards, must have an unfavourable effect; so that upon the whole, a piled foundation is the only precaution that can thoroughly be depended upon.

* It is also useful, and indeed often absolutely necessary, to have a continued foundation of solid masonry and woodwork, piled or not, according to circumstances, under docks for the repair of single ships, as also under the locks of canals, and all other small basons, from whence the external water is at times to be excluded by means of flood gates: and such foundations, when the breadth is small, may be composed of a single inverted arch; but when the breadth is very considerable, those parts only are curved, where the masonry of the foundation adjoins to that of the side walls, so that in the section of a work so constructed, two distinct portions of an inverted arch appear, which are at some distance from each other, and are not connected by any continued curve, but by a right line. The masonry of works of this description is usually made stronger than that of common wharfs. The reason is, that when a body of water is shut out, by artificial obstacles, from any space, much lower than the level of its own surface, if the fluid should be able to find some weak part or aperture, in or beneath the masonry or woodwork, by which it is excluded, it will endeavour to break through, with a force proportional to the difference of level; so that, unless the walls and foundations of such works, as have been mentioned, are of more than usual thickness, as well as of good materials, and executed with great care, they are liable to be blown up, as it is called, and in part destroyed, or rendered unserviceable, by the force of the water. Accidents from this cause have often happened in great works. To secure the foundations of the floodgates, which are in opposition to the excluded water, and which are considered the most vulnerable part, a transverse row of dovetailed piles is generally driven in front of them, that is to say, on the exposed side, and sometimes another parallel row is added in rear.

Such foundations sho d be formed by inver d arches, abutting against the said counterforts as piers; in the manner shown in the annexed figures, of wh h one represents the r r elevation of the masonry



only, of a common revetment, the other of a counterarched revetment, having foundations so constructed; an arrangement, whicl must be of advantage, even when piles are used; for by distributing the total weight of masonry, to be supported, over a greater number of them, it must evidently diminish the pressure upon each individual pile. With respect to the counterarched re-



In the locks of canals, a continued foundation of solid masonry is not always used, throughout the whole extent of the bason, but only in those portions which are immediately beneath the two flood-gates.

The banks and bottoms of canals, and ponds, are rendered watertight by puddling them, as it is called, which expedient may also be used to advantage in certain cases, in military works, and shall therefore be described.

Puddle is formed by taking a quantity of earth, and mixing it up with water, gradually poured upon it, to the consistency of mortar for building. It is applied to the spot intended, in horizontal layers or courses of about 9 inches in depth, and is mixed by men treading on it with mud boots, and stirring it with shovels. Each layer, when sufficiently worked up, is left to dry, until a man may stand on it without sinking: then a second layer of the same thickness is applied above the former, care being taken to unite them well by stirring and wetting the surface of the original work.

vetment, in particular, represented in our second figure, I conceive it to be preferable to the concave profile, described in the preceding chapter; which last-mentioned construction may also be adopted in soft soil, with the same view of increasing the base, and thereby more generally distributing the vertical pressure, upon a piled foundation.

It was remarked in a former chapter, that retained earth seldom presses in an unfavourable manner upon revetments, excepting when it has been acted upon by frost or rain. And indeed, whenever failures in revetments have been known to take place, although they may generally be traced to some defect, either in the original profile, or in the workmanship, the immediate and apparent cause has almost always been a violent rain storm, or series of continued bad weather. It is therefore of the utmost importance, to secure works of fortification against such accidents, which can only be done by a judicious system of well-constructed drains; and as a further precaution, all the slopes of parapets, &c., should be sowed with grass, it having been found by experience, that vegetation is very useful towards the preservation of earthen works, at least in a moist climate such as that of England. *

and thus the process of puddling is continued in successive layers, to the required height, three feet being in all cases a sufficient thickness. Clay and garden mould, or vegetable earth, are not good for forming puddle; the best kind of earth for that purpose being a lightish loam, mixed with coarse sand or fine gravel, all particles of which, exceeding the size of a musquet ball, should be rejected. Puddle, when suffered to become thoroughly dry, cracks, and loses its efficacy; but when properly made, and either brought into immediate use, or kept moist until required, it is impervious to water.

* As a proof of the tenacity which earth is capable of preserving, when it can be guarded from the effects of weather, may be mentioned the custom, which prevails at Gibraltar, of building the walls of dwelling houses with rammed earth, which being covered externally with a coat of plaster, are very durable, notwithstanding the great violence of the rains which often fall there. Latterly, some of the traverses, on the forti-

As the exterior surface of masonry chiefly decays through the action of weather upon the joints, it becomes an useful precaution to diminish the number of these as much as possible, in all the horizontal or sloping parts of the work, which are the most liable to suffer. For this reason, in walls, built with brick-work, it is always proper to cover the top, when exposed to weather, with some larger material, such as a stone coping, in the joints of which, it is desirable that a better cement than common mortar should be used. In this climate, about 1 foot of sod-work, over the top of a wall, is a good preservative against the effects of frost; and may therefore be used to cover the summit either of a counterscarp or scarp revetment, built with brick-work, when stone copings or cordons are considered too expensive.

Having now completely discussed the theory of revetments, and added as many practical details as appeared necessary, I shall

fications at the same place, have been formed in a similar manner. The above mode of construction is called tapia by the Spanish inhabitants, and probably is the best that could be adopted for parapets in a very hot climate The Castle of Badajos is partly built in the same manner.

Rammed earth is also used by the natives of India in their fortifications. In raising walls of this material, which they carry up nearly perpendicularly, they mix up each course, which is of moderate thickness, with water, and after beating it well, they allow it to dry, before another layer is applied. These mud forts, as they are called, have often proved great obstacles to the progress of our arms in the East. The desperate defences, made by some of them, are recorded in a book recently published, by an officer in the Bengal Establishment of the East-India Company's army, entitled "Observations on the Attack of Mud Forts."

That vegetation is useful towards the preservation of earthen works, is proved by the field works, thrown up at Upnor, near Chatham, for the purpose of exercising the junior officers and soldiers of the Royal Engineer Department in the operations of a siege. Such of these field works, as are left standing, after a certain time, lose their proper form, in consequence of the effects of weather, while the parapets and slopes of the permanent works remain perfect, by reason of the grass with which they are covered.

conclude this volume, by making some remarks upon the Theory of Arches, a subject, which is also usually considered as forming part of a course of fortification; and which appears to me to have been treated, by mathematical writers in general, in a manner by no means convincing or conclusive; for in this important inquiry, as well as in the former, they seem to have built upon hypothesis, instead of having recourse to experiment.

As the investigation of the properties of arches is certainly much more intricate, and complex; so the theories, formed upon this subject by speculative writers, are more at variance with each other than those upon revetments. But without entering into the merits of the various theories of arches, that have been published, in the formation of many of which, great talent and ingenuity have been displayed, I shall confine my observations to one only, which has been advanced in this country by some writers of established reputation, but which appears to me to be founded on such fallacious principles, that it may be useful to the reader to state my objections to it.

The doctrine now alluded to, was, I believe, first promulgated in this country by Emerson, who, in investigating the properties of arches, judged it convenient to consider the several arch stones, as perfectly polished bodies without friction, and the same preliminary hypothesis has since been adopted by some subsequent writers. In consequence of this assumption, which forms the basis of their theories, they have come to a decision, that semicircular arches, or others, springing from a horizontal plane, should be altogether condemned and rejected, as being unfit for practical purposes: for they maintain, that by the principles of pure mechanics, any polished body without friction, placed on a horizontal plane of the same nature, has no lateral resistance, but may be moved from its place by the smallest possible power; and therefore, they argue, that the two extreme or lowest arch-stones of the semicircle, or of any other curve, springing from a horizontal plane, can have no power

whatever of resisting the thrust or lateral pressure of the other arch stones; so that such arches must necessarily give away at their haunches, unless loaded with infinite weight, a thing which in practice is impossible. Now, although this conclusion might certainly hold good, in respect to the imaginary arch-stones, above assumed for the sake of hypothesis, it will be found by experiment, that common freestone rubbed smooth, but not polished, if laid upon a horizontal plane of the same substance, without mortar, will require a power of about two thirds of its own weight to overcome its lateral resistance; and if prepared in the manner usually done by workmen for building, that is to say squared but not rendered quite smooth, it will require a power nearly equal to three fourths of its own weight to overcome the said resistance.* And therefore, since the friction of stone, in the state in which it is prepared for building, is so very considerable, even without noticing the vast additional resistance derived from the cohesion of the mortar; † it is not to be wondered at, if those theories of

* Such were the results of a series of numerous experiments, tried by me, in Malta, in the year 1805, for the purpose of ascertaining this subject, with squared stones of various sizes and proportions, and of a soft quality resembling Bath stone; the largest of which was 2 feet 6 inches long, 2 feet wide, and 1 foot thick, and weighed 626 lbs. It also appeared, that the friction or lateral resistance of any stone, in opposition to a power, tending to move it along a horizontal plane, was in all cases in proportion to its own weight, and to the state of smoothness of the two surfaces, that came in contact with each other, as mentioned in the text; without any reference to the actual dimensions or superficial contents of the said surfaces.

† In some extensive vaults near Bayae in the Kingdom of Naples, said to have been constructed by the Emperor Nero, which consist of a series of groined arches resting upon square pillars, I observed, that although the lower half of one of these pillars was cut entirely away, the upper part of the said pillar, together with the four arches, which depended upon it for support, remained as firm as any of the others, by reason of the cohesion of the mortar. When Abukir Castle was attacked by the British in 1801, a breach was effected in the side of a high tower, forming a very large hole or

arches, in which this friction is entirely disregarded, should have led to a totally erroneous conclusion; and such I conceive to be the decision, before quoted, against the use of all arches springing from a horizontal plane; a decision, which in fact is contradicted by daily experience, for it is scarcely possible to walk out without seeing arches of this description in a strong and serviceable state; and indeed we know, that there are many instances of semicircular arches, nearly 2000 years old, which are in perfect preservation to this day, and capable of supporting the greatest possible weight that can be applied to them.

It is further to be remarked, in opposition to the said theories, that the piers and abutments of arches are, in real practice, in ninety-nine cases out of a hundred, built of the same materials, whether stone or brick, and are cemented with the same kind of mortar, as the arches themselves. If therefore, the stones of an arch are to be considered as perfectly polished bodies without friction, it follows, that the stones of the piers, which are of exactly the same nature, ought also to be so considered, otherwise the theory must necessarily be inconsistent with itself. But as the courses of masonry in the piers of arches are always built horizontally, * each of the uppermost stones of the piers of a parabo-

opening in the wall, and yet the upper part of the masonry stood firm, from the same cause. Every one may have had an opportunity of observing, in walls built on the sea coast or on the banks of rivers, that they are often undermined, to a considerable extent, by the water; and yet that the upper part of them will remain good. For example, about 190 superficial feet of the foundation of one of the exterior walls of Rochester Castle have been entirely washed away by the Medway, and yet the rest of the wall, although thus undermined, remains perfectly firm.

* It is well known, that masonry, in general, is built in horizontal courses, without taking any precaution, further than what arises from the weight and friction of the materials, and the cohesion of the mortar, in order to prevent a lateral motion; and, indeed, there is no ordinary pressure or power, that can possibly act upon a mass of masonry, of a certain solidity, such as

lic or catenarian arch, rests upon a horizontal plane; and consequently, if the said stones are without friction, they can have no lateral resistance, or in other words, they can have no power what-

the pier of a bridge, that will ever cause the upper part of the said mass to separate from the lower part of it, by moving horizontally upon the course immediately beneath. On the contrary, when walls have failed, from a want of due strength, whether as piers or revetments, they have always been torn asunder in a very different manner from the above, the fractures being irregular and oblique, never horizontal.

There are, therefore, only two cases, in common use, in which precautions are taken to prevent a horizontal motion: 1st. In thin walls the height of which is inconsiderable, such as the parapets of bridges, it is usual to connect all the adjoining stones together, by iron cramps or dowels bedded in lead; a precaution, which, in higher or more substantial walls, would be superfluous. 2dly. In forming the shafts of columns, when composed of several pieces or horizontal courses, of stone or marble, it is usual to introduce into each joint, a joggle of a cubical form, of hard stone or metal, which is let, one half of its depth into the lower, and the remainder of it into the uppermost of the two stones, that are to be put together: all the portions of the column being previously mortised, both at top and bottom, for receiving the said joggles, which break the continuity of the horizontal joints, and when properly fitted, must, therefore, effectually prevent all lateral motion.

But although not usual in common buildings, excepting in the two cases, that have been stated, such precautions have sometimes been carried to a great extent, in buildings of a peculiar nature, that require extraordinary care in their construction, as being exposed to more than ordinary risk. The construction of the Edystone light-house, in particular, affords an example of a combination of all the most effectual means, that could have been adopted, for uniting the several component parts of the edifice into one compact body with the rock upon which it is founded. In the lower and solid part of this tower, the various stones of each horizontal course, are all dovetailed into each other; one large center stone, from whence they radiate, forming the key of the whole; and thus the numerous pieces, composing each horizontal course, are united, as it were, into one large stone; and the bottom ones are, by the same method, solidly grafted into the rock. Each course is pinned down to that immediately below it by oak trenails, two of which are driven through every stone, besides which the continuity of the horizontal joints is broken by marble joggles,

ever of resisting the thrust of the arch stones. Therefore by their own theory, when it comes to be fairly applied, the parabolic, catenarian, and other arches of equilibration, recommended by the mathematical writers, alluded to, are liable to the very same objection urged by them against the semicircle, that is to say, unless their piers are loaded with infinite weight, these arches ought to give way.

I thought it right to make these observations, in order to put young Engineers, and others, who may be employed in practical arts, on their guard against a theory, which having been maintained by men of merited reputation, might continue to make an impression on the public mind, so long as it remained uncontroverted.

both in the center, and at certain intervals, towards the circumference. In the hollow parts of the tower, the various stones, composing the circular wall, not being more than 13 inches thick, are secured not only by marble joggles, but also by iron cramps, but without trenails; and those particular courses of the circle, against which four flat dome arches of about 12 feet span abut, are strengthened by endless iron chains, bedded by means of melted lead, into a circular groove, cut all round in the middle of the masonry; which has been thus enabled to resist the lateral pressure of the said arches. These are of a very peculiar construction, the joints of the several arch stones being not only cut according to the curve, but also in a dovetailed form. The central stone of each arch, with which all the others are connected in this manner, is perforated by a circular hatchway, which serves for the purpose of communication. Such are the general precautions that were adopted to consolidate and secure this celebrated edifice, which is built on a small rock usually covered at high water, even in a perfect calm, in a situation, which in a gale is exposed to the whole violence of the Atlantic Ocean. All the exposed parts are built of Cornish moorstone or granite, the interior of the solid portion of the tower, only, being of Portland stone. The cement used was Puzzolana, mixed with Lyas lime, in equal proportions.

It is said that in Blackfriars bridge, built by Mr. Mylne, not only the horizontal joints of the piers, but also the oblique joints of the arch stones, have been dowelled by cubical joggles of hard stone. I am not aware, that this expedient has been adopted in the construction either of the piers or arches of any other bridge, and, indeed, it appears to me to be superfluous.

Indeed, I conceive that it would be greatly for the benefit of the arts, if it were agreed, that every theory, in which mathematical reasoning is applied to practical subjects, should be disregarded and set aside as a mere speculation, or exercise of ingenuity, unless the author grounded his doctrines upon, or supported them by, a sufficient number of satisfactory experiments, tried by himself or others. With respect to the strength of arches, in particular, I shall conclude by observing, that every arch, actually constructed, which is now standing, in a state of preservation, must be allowed to be an experiment of the most satisfactory nature, by which we may judge of the proportions and dimensions necessary, for arches of a similar form. The state of our knowledge upon this subject is therefore not by any means so limited and imperfect, as upon the former subject of military revetments. For a vast number of arches on a great scale, and of various forms and dimensions, have been executed with success in every civilized country, accurate and detailed descriptions of which can easily be procured,* so that

* The historical and practical parts of the article "Bridge," in the Edinburgh Encyclopædia, written by Mr. Telford, contain ample information upon this important subject.

To the same gentleman, I am indebted for the dimensions of some of the profiles of revetments built by civil Engineers in this country, and described in the notes to the preceding chapter, which I had not myself any opportunity of ascertaining personally. The various military works, whose dimensions are given in this book, were constructed by officers of the Corps of Royal Engineers. Their names are not mentioned, because I have not in all cases been able to discriminate, whether the projects of the casemates, powder magazines, towers, revetments, &c., described, were determined by the Committee of Fortifications, which is composed of a certain number of senior officers of Engineers, acting under an Inspector General, who also commands the Corps, or whether they may have been suggested by individual officers, commanding at the various stations, where the works were carried on.

I have been minute in stating dimensions, because it must be much more satisfactory to those, who have to decide upon projects of new works,

the Engineer having these examples before him, can run no risk of failure, provided that he does not make the thickness of his piers, or other proportions, upon which strength depends, less than those, that have been found to answer under similar circumstances. Without perplexing himself, with attempting to discover the form of an arch of equilibration, that is to say, one so nicely poised upon its piers, as to be barely capable of supporting itself, and nothing more; a form which is not to be recommended either for civil or military purposes; he may therefore fearlessly adopt either the

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to have descriptions of similar works already executed, before them, the advantages or disadvantages of which may be ascertained by inspection or by inquiry; than if they were left to form their judgement, merely according to general rules, unaided by practical examples.

I shall conclude by describing the general profile of the revetments of the new works of Plymouth Dock. The scarp revetment is every where 30 feet high, and has a continued exterior slope of $\frac{1}{8}$th, but its thickness varies in proportion to the height of earth above it, which in some parts is 2 feet greater than in others. In the former, the thickness of masonry at the base is 10 feet; in the latter, it is 9 feet 6 inches. In both cases, the back of the revetment is built perpendicularly in rear, to the height of 26 feet. From thence upwards, the thickness of the remaining 4 feet of masonry, being reduced at the above height, by an offset, varies from 3 feet 6 inches to 5 feet, which is the general thickness at top. Thus the mean thickness of the scarp revetment, in some parts, rather exceeds $\frac{1}{4}$th of the total height of masonry, whilst in others, it falls somewhat short of that proportion. The counterforts are all 5 feet wide, 6 feet long, and 26 feet high; and are placed at central intervals of 20 feet apart. The above profile may be considered a full scarp revetment, as there is no where any great height of earth above the masonry. The counterscarp revetment is built without counterforts, and is, in some places, 25 feet high, with about 1 foot of earth over it, and there it is 9 feet thick at the base. In other parts, where the height is 20 feet, it is only 7 feet thick at the base. It has every where an exterior slope of $\frac{1}{8}$th, and is perpendicular in rear, so that its mean thickness varies from about $\frac{3}{10}$ths, to $\frac{17}{60}$ths, of the height. In some few places, the heights, both of the scarp and counterscarp revetments, are greater, and the slopes and other dimensions vary from the above profiles, which however apply to the works in general, and are according to the last decision of the Committee of Fortifications.

semicircle, the ellipse, the circular segment, the parabola, the catenarian curve, &c., &c., as he judges convenient: for since all these forms, which have been enumerated (and indeed many more) have been tried, and all have stood; it follows, that none ought, in reason, to be unconditionally condemned, and none to be unconditionally preferred to all the others, but that in one case one form, in another, another may be chosen, as the most suitable, either with a view to beauty, in ornamental buildings, or from motives of strength, economy, or conveniency, in others. Thus, for example, to draw a practical comparison between the flat circular segment, and the parabola, whose rise is equal to half its span, the former is, by far, the most suitable for a bridge over a great river, whilst the latter may be allowed to be a much better form for a bomb-proof powder magazine.

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ERRATA IN VOL. III.

Page 107, Note, line 2. *For* 124—*read* 104

- - 450, line 16. *For* point, 3—*read* point, 4

— 517, line 4. *For* A F—*read* A f

— 558, line 7. *For* G E F—*read* G C F

- - 561, Note, continued from the preceding page. *Erase the last sentence, commencing with the words,* Compare also

— 574, TABLE II. In the column of stability without shingle. *For* 53—*read* 50.

— 618, second line from the bottom. *For* 280, 281, and 282—*read* [illegible], and 294

621, RULE VII, line 6. *For* counterforts equal—*read* counterforts equal in length

— 621, REMARK, line 2. *Experiment 401, in Table XIII, although very nearly, is not exactly, applicable to the case, which it has there been quoted for the purpose of proving. The point in question is, however, fully proved by several of the other experiments, contained in the Tables.*

— 661, Note, continued from the preceding page, line 5. *For* VI. VII. and VIII.—*read* V. VI. and VII.